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**EDGEWOOD ARSENAL
TECHNICAL REPORT**

EATR 4430

**SPECTRAL ABSORPTION CHARACTERISTICS
OF THE MAJOR COMPONENTS OF DUST CLOUDS**

by

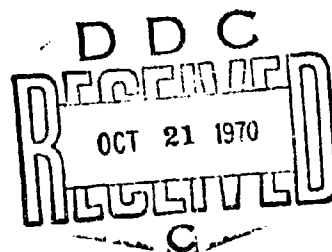
D. F. Flanigan

H. P. DeLong

September 1970



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EDGEWOOD ARSENAL
Defense Development and Engineering Laboratories
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Edgewood Arsenal, Maryland 21010**

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COMPONENTS OF DUST CLOUDS

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Dennis F. Flanigan
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Task 1C622401A10202

DEPARTMENT OF THE ARMY
EDGEWOOD ARSENAL
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Detection and Warning Laboratory
Edgewood Arsenal, Maryland 21010

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FOREWORD

This report discusses research that was authorized under Task IC622401A10202, Chemical Agent Warning and Detection Techniques (U). It covers work from May 1968 through December 1969. The original record of this research is retained at Edgewood Arsenal in notebooks 6764 and 8031 and in related spectrophotometer charts. In addition, absorptivity coefficients of some soil samples are retained at Edgewood Arsenal on magnetic tape.

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DIGEST

It is well known that dust clouds selectively absorb radiation in the 700 to 1300 cm^{-1} atmospheric window region. Studies have shown that dust clouds are composed of the same minerals as surface soils, although in different proportion. We have examined 70 soil samples from a number of locations around the world to determine their composition and spectral characteristics. The results indicate that there are five major components that selectively absorb radiation in the 700 to 1300 cm^{-1} region. These are three clay minerals, silica, and calcium carbonate. Absorptivity coefficient spectra of representative soil samples are given in the body of the report, and transmission spectra of all the samples are presented in the appendix.

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SPECTRAL ABSORPTION CHARACTERISTICS OF THE MAJOR COMPONENTS OF DUST CLOUDS

I. INTRODUCTION.

The 700 to 1300 cm^{-1} region is becoming more widely used for horizontal-path infrared measurements. The Army is investigating devices for the detection of atmospheric pollutants using their characteristic infrared absorption bands in this region. These devices may operate passively, using background radiation,¹ or actively, using laser radiation reflected from the background.^{2,3}

Naturally occurring dust clouds also absorb in this region and thus interfere with the operation of detection instruments and other horizontal-path infrared devices.

The primary objective of this program was to determine the variety of minerals present in surface dust clouds. These were determined using the standard potassium bromide (KBr) pellet technique and a laboratory spectrophotometer. We used a rapid-scan spectroradiometer, however, to demonstrate that the spectral absorption properties of minerals in dust clouds are similar to those of the same minerals in a KBr matrix.

II. EXPERIMENTATION.

This study was conducted entirely in the laboratory using the following samples: Soils from a world-wide collection by the U.S. Department of Agriculture; soils from five military installations; and finely ground industrial minerals from Whittaker, Clark, and Daniels, Inc., New York, New York.

The spectra of airborne dusts were obtained using a rapid-scan spectroradiometer. This instrument was designed and constructed to Edgewood Arsenal specifications by Exotech Inc., Rockville, Maryland. The wavelength selection element is an Optical Coating Laboratories, Inc., Santa Rosa, California, circular variable filter (CVF) wheel. The CVF has a split linear wavelength range of 3 to 6 μm and 7 to 14 μm . Resolution is approximately 2% of the wavelength.

For these tests a scanning speed of 4 seconds per revolution of the CVF (2 seconds for the 7- to 14- μm range), a He-cooled Ge:Hg detector, and a remote Nernst glower infrared source were used. The dust cloud was generated in a 3.7-meter long, 0.3-square-meter, open-ended, sheet-metal duct. Results are qualitative.

The spectra of dusts in KBr pellets were taken with a Beckman IR9 spectrophotometer equipped with a Datex digital data recorder.

The soil samples contained particles of all diameters to several millimeters. Only particles smaller than 10 μm were of interest because only these have significant spectral absorption effects. In addition, the composition of the larger particles would be mostly quartz. Consequently, the soil samples were filtered, not ground.

Two filtering methods were used. In the first, a soil sample was placed in distilled water and boiled to break up agglomerates. The suspension was filtered through Whatman No. 4 filter paper. The filtrate was then evaporated over a low flame with care to assure no degradation of the sample. The dried soil sample and the finely ground KBr powder were mixed with an agate mortar and pestle to minimize contamination. Care was taken to apply enough pressure for mixing but not enough to grind the sample. The resulting mixture was pressed into a KBr pellet using standard techniques.

In the second method, a glass tube 45 cm long and 5 cm in diameter was used with a filter paper at one end and a ceramic filter holder at the other. The column was placed in a vertical position with the ceramic filter holder, containing the soil sample, at the lower end. An airstream was passed through the sample. The air agitated the soil sufficiently to collect a specimen of dust on the filter paper at the upper end of the column. A portion of this specimen was mixed with the KBr powder and pressed into a pellet.

Spectra taken of samples prepared by either method were essentially identical. Most of the samples were prepared using the more convenient wet method.

The transmission spectra were digitized, and absorptivity coefficients were calculated from the Beer-Lambert Law as a function of wavenumber and were plotted accordingly.*

*The spectral data were gathered for the evaluation of dusts as interferences in the operation of infrared pollutant detection systems. This evaluation requires that the data be entered into a computer as a part of a detector simulation program. Therefore, the spectral data were digitized as a continuous set of transmittance values. This set was used to calculate a set of absorptivity coefficients using the Beer-Lambert Law.

If the Beer-Lambert Law is to give an accurate representation of transmittance, the absorptivity coefficient must be constant over the required transmittance range. This is true to a good approximation for gases and liquids, but not for solid particles. Jones⁴ gives a detailed description of the variation of the absorptivity coefficient for changes in particle diameter and sample transmittance. For a given weight of material the projected area of a powder will increase as the average particle diameter increases. This decrease in projected area will make the powder less effective as an absorber of specific wavelengths. We do expect that the absorptivity coefficients have some errors of this type. If so, the peak absorptivity coefficients may be stronger by 10% to 20%.

There is an additional complicating factor for soil samples. They are composites of a variety of compounds whose relative concentrations are not fixed. Thus, even if the absorptivity coefficients were as good as those for liquids or vapors, they would be valid for only a particular mixture.

Despite these limitations, absorptivity coefficients were calculated for a large number of soils for the following reasons. (1) Transmittance values could not be used directly because a wide range of concentrations had to be simulated. Over this wide range, the use of absorptivity coefficients is superior to a linear extrapolation of transmittance values. (2) By using a large number of compounds, the random concentration variations should average out.

III. THE SPECTRA OF AIRBORNE DUSTS.

There are several questions to be answered if the spectra of airborne dusts are to be compared with the spectra of dusts in a KBr matrix. Does the KBr matrix suppress scattering and enhance spectral absorption? Does it introduce distortion of bands or change their peak wavelengths?

Phillippi⁵ discusses these optical effects. While these effects may be important, we do not believe they alter our basic conclusions for the following reasons. (1) Bands are fairly symmetrical (a criterion for nondistortion). (2) Peak locations agree with those in the literature. (3) The airborne dust spectra and the KBr dust spectra agree.

Figure 1 shows a freon calibration spectrum illustrating the response of the system to a known gas. Figure 2 presents the spectrum of a finely ground industrial kaolin. Kaolin, which will be discussed in more detail later, is a major component of many soils, and consequently, of many dust clouds. A comparison of figures 1 and 2 shows that the kaolin absorbs specific wavelengths about as effectively as freon. Furthermore, the kaolin spectrum shows little, if any, scattering. Figure 3 shows spectra for samples taken from two different locations at Dugway Proving Ground, Utah. These soil samples were sized only by the rapid fallout of the larger particles during the course of the experiment. They show that the extinction is still largely spectral absorption.

Comparison of figures 2 and 3 with the KBr spectra of figure 4 indicates that band shapes and positions of the dust in the two media agree within limits of resolution and wavelength accuracy of the spectroradiometer. The comparison is particularly good between airborne kaolin dust (figure 2) and kaolin dust in a KBr pellet (soil sample 58 in figure 4b).

These preliminary spectroradiometer results lend credence to the KBr data to be presented in the next section. Consequently, we believe that the question of the spectral characteristics and varieties of dust can be successfully approached using the KBr pellet technique.

IV. THE SPECTRA OF DUSTS IN KBr PELLETS.

Selected absorptivity coefficient spectra of the soil samples are shown in figure 4. The transmission spectra for all 70 soil samples and some industrial minerals are shown in the appendix, figures A-1 through A-74.

The spectra of almost all of the soil samples were very similar. Most spectral features could be attributed to five compounds: The three clay minerals, silica, and calcium carbonate. This was surprising in view of the large number of available minerals.^{6,7}

V. THEORY.

The following discussion was gleaned from a number of sources, including geology texts^{8,9} describing generally accepted geological theory.

If an airborne dust is to be an effective spectral absorber of infrared radiation, particle diameters should be less than 10 μm . In addition, there should be a large number of these

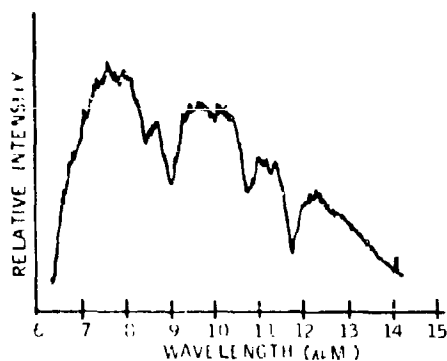


Figure 1. Spectroradiometer Spectra of Freon Gas

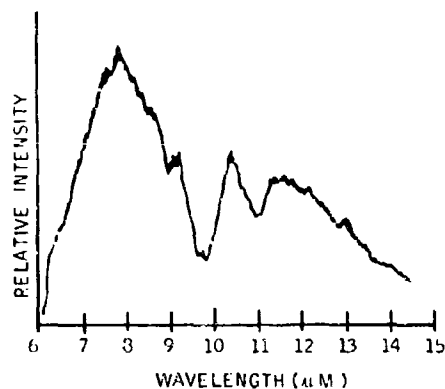


Figure 2. Spectroradiometer Spectra of Industrial Kaolin

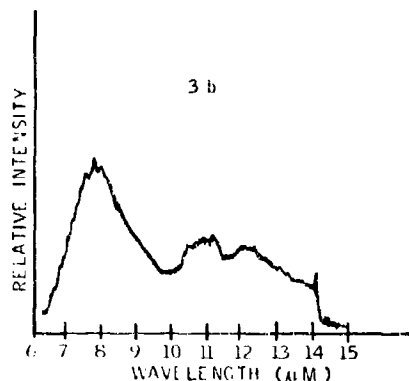
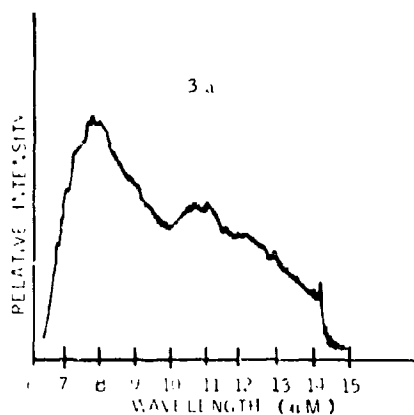


Figure 3. Spectroradiometer Spectra of Samples From Dugway Proving Ground, Utah
(a) road sample, (b) test grid sample.

particles. Small particles in large numbers with wide geographical distribution are generally limited to the weathered products of minerals. The weathered products of most common minerals are the clay minerals, metal oxides, and silica.^{10,11} These minerals are stable. Either they do not undergo further chemical or physical breakdown, or such processes are in equilibrium. Calcium carbonate is also a stable weathered product commonly found in dry areas.¹²

Most features in the transmission spectra (400 to 4000 cm^{-1}) of the soil samples could be explained by the presence of the clay minerals, silica, and calcium carbonate. Our spectra, however, consistently showed a small band at 1380 cm^{-1} , which we identified as

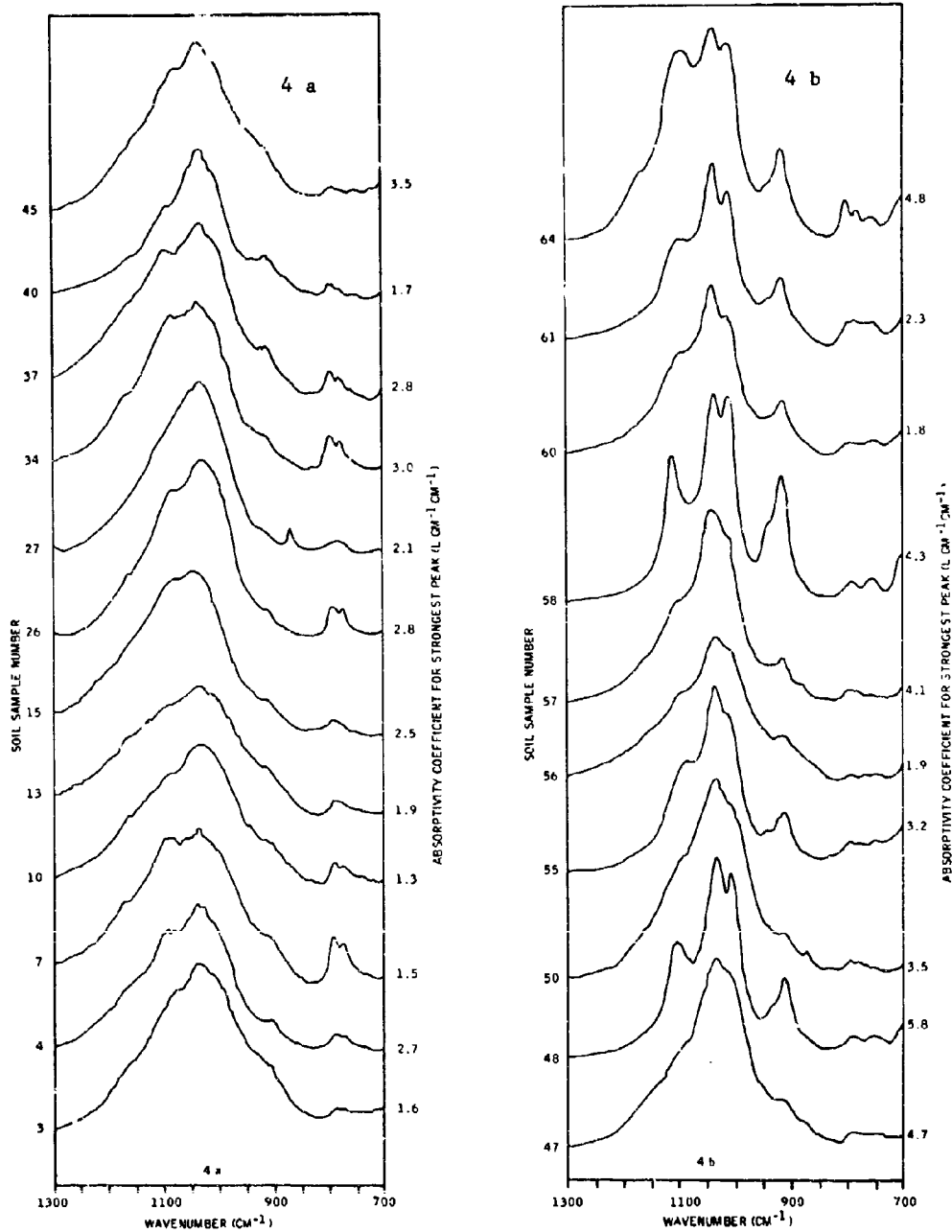


Figure 4. Spectra of Selected Soil Samples

Spectra are absorptivity versus wave number, where absorptivity was calculated from the Beer-Lambert relationship. Spectra were normalized by dividing each value of absorptivity by the peak value of the largest band

potassium nitrate.¹³ The geology texts do not mention this material specifically. Its presence does not appear to be affected by either the wet or the dry method of sample preparation, but it might arise from a chemical exchange between components of the soil sample and the KBr pellet material. Hoidale and Blanco¹⁴ also noted a reaction between the nitrate and the KBr. Similar exchanges are reviewed by Lawson.¹⁵ Potassium nitrate also has a band at 824 cm^{-1} , but its absorptivity is low and therefore not visible in our spectra.

Other studies have shown that dust clouds are composed of the same minerals as the surface layer of soil, although in different proportions. Barrett et al.¹⁶ found kaolinite and silica in samples deposited on various surfaces above ground. The samples in this study were compositionally biased toward clay because of the much larger average size of the silica particles. Hoidale and Blanco,¹⁴ in studies conducted in the American southwest, found silica, calcium carbonate, sodium nitrate, and the three clay minerals in samples filtered from the atmosphere. Sakabe et al.¹⁷ found essentially the same results in samples taken in Tokyo.

There are, of course, innumerable other particles in the atmosphere. These particles can be organic, inorganic, or biological. Sources of such particles include the sea, forest fires, volcanoes, industry, and even meteoric dust.¹⁸ Occasionally, the surface concentrations of these particles can be very high. Normally, however, the airborne concentration by weight of such materials is quite low relative to the soil minerals.

Dry areas occasionally contain surface deposits of unusual minerals. Blanco and Hoidale¹⁴ found evidence of sulfates in dry areas; over the total geographical range of their studies, however, such minerals were of little consequence.

VI. DESCRIPTION OF MINERAL DUSTS.

A. The Clay Minerals.

The clay minerals are divided into three major groups: Kaolinite, illite, and montmorillonite. These are hydrous aluminum silicates. Kaolinite has a well defined composition; however, the compositions of illite and montmorillonite are variable. Detailed discussions of the chemical structures of all three can be found in Dapples⁸ and Mason.⁹

Physically, the clay minerals are aggregates of extremely minute crystal particles. These particles range in diameter from 0.1 to $100.0\text{ }\mu\text{m}$, but the most common sizes are between 0.1 and $1.0\text{ }\mu\text{m}$.¹⁹ Sample 58 in figure 4b is almost pure kaolinite. (See also figure A-71.) Its spectrum is well defined and sufficiently detailed so as to be easily identified. Sample 27 in figure 4a is probably montmorillonite; illite is very similar, but the major peak falls at 1030 cm^{-1} instead of 1040 cm^{-1} .²⁰ Spectra of these minerals are presented by Hunt et al.⁶ and indicate that illite and montmorillonite are poorly defined and very similar. Some subtle differences exist,²⁰ but are of no apparent consequence for atmospheric absorption spectroscopy.

All three clay minerals have one characteristic in common: One or more very strong bands exist in the region between 1000 and 1050 cm^{-1} . These bands are attributed to the framework vibrations of the silicon-oxygen group.²¹ The positions of the principal infrared peaks of the clay minerals in the 700 to 1300 cm^{-1} region are given in table I. These were assigned from values given in the literature and from spectra taken of the industrial minerals.

Table I. Peak Positions and Intensities of the Infrared Bands of the
Common Dust Minerals

[W: weak, M: medium, S: strong, VS: very strong]

Kaolinite			Illite			Montmorillonite		
cm^{-1}	μm		cm^{-1}	μm		cm^{-1}	μm	
700	14.29	M	913	10.95	M	913	12.75	M
755	13.25	W	1031	9.7	VS	1040	9.6	VS
790	12.66	W	1117	8.95	M*	1117	9.95	M*
913	10.95	S						
938	10.66	M						
1010	9.90	VS						
1035	9.66	VS						
1100	9.09	S						
1115	8.97	S						
Silica			Calcium carbonate					
780	12.67	M	714	14.0	W			
800	12.50	W	845	11.83	W			
1090	9.17	VS	873	11.45	S			
1175	8.51	S*	1430	6.85	VS**			

*Shoulder.

**Extends well into the 700 to 1300 cm^{-1} region.

Peak positions of the soil samples frequently do not agree exactly because the overlap of strong bands of different minerals cause apparent shifts.

B. Silica.

Silica occurs in several common crystalline varieties that have essentially the same infrared spectrum.⁶ A commercial silica also has the same spectrum (see figure A-73). The peak positions are given in table I.

Silica is one of the most resistant of all minerals to weathering.²² It occurs in all sizes ranging from silt to pebbles in weathered soils.²³ In addition to these relatively large particles, some weathering processes apparently produce silica particles of colloidal dimensions.²⁴

Our spectra of airborne dust clouds do not deny or confirm the existence of these fine particles. In the "synthetic atmospheric dust spectrum" developed by Hoidale and Bianco,¹⁴ silica constituted about 6% of the total sample weight. The KBr transmission spectra of the soil samples show little scattering at high wavenumbers and strong absorption at 1090 cm^{-1} . This is supporting evidence for the existence of silica particles of colloidal dimensions.

C. Metal Oxides.

Ferric oxides occur in two stable forms. Hematite and a hydrated ferric oxide, limonite. Hydroxides also occur, but these weather to the hydrated oxide. All three are responsible for reddish-colored sediments and rocks.²⁵

A spectrum (figure A-74) was taken of a sample of ferric oxide from Whittaker, Clark, and Daniels, Inc. Three bands were found. One occurred at 1025 cm^{-1} , the other two at 470 and 545 cm^{-1} . The 1025 cm^{-1} band is only about 2% of the intensity of the silicate bands, which occur in the same region, and consequently is undetectable. The 470 cm^{-1} and 545 cm^{-1} bands are about 10 times stronger than the 1025 cm^{-1} band, but generally are masked by kaolinite bands in that region. In any event, ferric oxide would appear to be of little consequence in the 700 to 1300 cm^{-1} region.

Certain areas of the world contain high concentrations of aluminum and titanium oxides.²⁶ We did not run spectra of these minerals because we had no evidence that they were of consequence in the 700 to 1300 cm^{-1} region.

D. Calcium Carbonate.

Calcium carbonate is generally formed by the dissolution of the mineral calcite. It is not subject to other chemical weathering processes. Normally, the calcium carbonate is carried downward through the soil and deposited at some lower level. In very dry regions, however, it does occur on the surface. Between rains in these regions, the normal flow of water is upward. This movement carries the dissolved calcium carbonate to the surface, where it occurs in a deposit known as "caliche." Caliche commonly occurs as a crust in desert soils.²⁷ This crust contributes particles to the atmosphere that can be detected using infrared techniques.¹⁴

Calcium carbonate has a very strong band at 1425 cm^{-1} (figure A-72). Although the peak of this band is well outside the region of interest, the shoulder extends into the 700 to 1300 cm^{-1} region. There is another band at 875 cm^{-1} that is about one half the intensity of the 1425 cm^{-1} band and much narrower. (See sample 54, figure 5.)

VII. DISTRIBUTION.

A crude but useful generalization of soil distribution can be made by defining three conditions of temperature and humidity. Condition 1 is characterized by a cold, wet climate. Surface soils in these areas are composed of silica and illite. Kaolinite can also occur, but generally in small quantities.²⁷ Condition 2 is characterized by extreme heat and humidity. Soil weathering is most intense under these conditions. Kaolinite is the only clay present, and little silica is found. (Extreme heat and humidity are the only conditions under which silica is not stable.²⁸) Concentrations of metal oxides are high, but this has little effect on the infrared spectra in the 700 to 1300 cm^{-1} region. Condition 3 is characterized by aridity. Temperatures can be either hot or cold, but weathering proceeds slowly because of limited moisture. The common soil minerals are silica, montmorillonite, and calcium carbonate;²⁷ but all dust minerals can be found in arid regions.¹⁴

Table II presents an analysis of components of our soil samples by inspection of their infrared spectra. Illite and montmorillonite were treated as one material because of the

difficulty in differentiating between the two by infrared techniques. The presence of very small quantities of kaolinite could be detected by bands in the 3600 cm^{-1} region. Similar quantities of illite and montmorillonite could not be detected.

In general, the results shown in table II agree with the soil distribution theory just outlined. Samples from northern latitudes contain large amounts of silica and montmorillonite or illite, possibly with small amounts of kaolinite. Moving southward, the kaolinite content increases in the wetter areas until it becomes predominant. Even far south, very dry areas contain little kaolinite.

Six spectra indicated that the samples contained appreciable amounts of calcium carbonate. Three (samples 14, 27, and 35) were from dry or desert areas. The others (samples 2, 9, and 54) came from regions of relatively high rainfall. The source of the latter samples is not in accord with the generally accepted geological theory. There are explanations for two of the anomolous samples. The almost pure calcium carbonate of sample 54, figure 5, (from South Miami, Florida) probably resulted from the deposition of marine organisms. Sample 2 from Vadsø, Norway, came from a site that is known to have been excavated during World War II.

VIII. CONCLUSIONS.

A typical dust cloud contains few minerals in sizable quantities. Only five compounds, which absorb in the $700\text{ to }1300\text{ cm}^{-1}$ region, are likely to be encountered. These are the clay minerals, silica, and calcium carbonate.

Airborne dusts occasionally contain other minerals, that absorb in the $700\text{ to }1300\text{ cm}^{-1}$ region; but in most locations these should not be significant spectral factors in the operation of short horizontal-path infrared instruments.

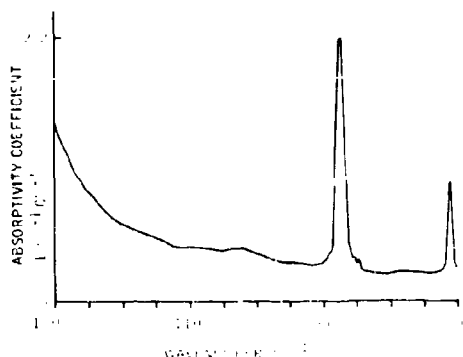


Figure 5. Spectrum of Soil Sample 54
This sample is almost pure calcium carbonate.

Table II. Relative Concentrations of the Common Dust Minerals in the Soil Samples
[T: trace; L: low; M: medium; H: high]

No.	Location	Kao	Ill Mont	Sil	CaCO ₃
1	Barrow, Alsk.		H	H	
2	Vadso, Nor.		H	M	H
3	Baroufoss, Nor.		H	H	
4	Fairbanks, Alsk.	T	H	H	
5	Reykjavik, Ice.		M	H	
6	Oslo, Nor.	T	H	H	
7	Edmonton, Can.	T	H	H	
8	Longueville, Fr.	T	H	H	
9	Paris, Fr.	T	H	H	L
10	Port Angeles, Wash.	T	H	H	
11	Mandan, N. Dak.	L	H	H	
12	St. Laurent, Fr.	T	H	H	
13	Longview, Wash.		H	H	
14	Bozeman, Mont.		H	H	L
15	St. Paul, Minn.		H	H	
16	Orono, Maine		H	H	
17	Corvallis, Oreg.		H	H	
18	Burlington, Vt.		H	H	
19	Rapid City, S. Dak.	L	H	H	
20	Florence, It.	L	H	H	
21	Boise, Idaho	T	H	H	
22	Madison, Wisc.	T	H	H	
23	Rochester, N. Y.	T	H	H	
24	Ithaca, N. Y.	T	H	H	
25	Amherst, Mass.		H	H	
26	Detroit, Mich.		H	H	
27	Logan, Utah		H	L	L
28	Des Moines, Iowa			H	
29	Kingston, R. I.		H	H	
30	University Park, Pa.	L	H	H	
31	Salt Lake City, Utah	T	H	H	
32	New Brunswick, N. J.	T	H	H	
33	West Lafayette, Ind.	T	H	H	
34	Columbus, Ohio	T	H	H	
35	Ankara, Tur.	T	H	H	
36	Springfield, Ill.	T	H	H	
37	Derby, Colo.	L	M	H	
38	Newark, Del.		H	H	
39	Morgantown, W. Va.	M	M	H	
40	Manhattan, Kans.	T	H	H	
41	Baltimore, Md.	M	M	H	
42	Lexington, Ky.	L	M	H	
43	Tulsa, Okla.	L	M	H	

Table II. Continued

No.	Location	Kao	Ill Mont	Sil	CaCO ₃
44	Raleigh, N. C.	H		L	
45	Tokyo, Jap.	T	H	H	
46	Little Rock, Ark.	M	M	H	
47	Los Angeles, Calif.	L	H	H	
48	Atlanta, Ga.	H		L	
49	Newton, Miss.	M	H	H	
50	Tucson, Ariz.	T	H	M	T
51	Waco, Tex.	L	H	H	
52	Alexandria, La.	T	H	M	
53	Jacksonville, Fla.	T	H	H	
54	South Miami, Fla.				H
55	Oahu, Haw.	H		L	
56	Manila, Phil.		H	H	
57	Panama Canal Zone	M	M	H	
58	Leedon Park, Singapore	H		L	
59	Singapore	H		L	
60	Muguga, Kenya	H		L	
61	Katherine, Austl.	H		M	
62	Salisbury, Rh.	H		L	
63	Antofagasta, Chile			H	
64	Durban, S. Afr.	H		L	
65	North Auckland, N. Z.	H		M	
66	Ft. McClellan, Ala.	H		M	
67	Ft. Benning, Ga.	H		L	
68	Ft. Sill, Okla.	M	M	M	
69	Yuma Proving Grounds, Ariz.	T	H	M	L
70	Edgewood Arsenal, Md.	H		L	

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24. Mason, B. *op. cit.*, p 149.
25. Dapples, E. C. *op. cit.* p 155.
26. *Ibid.*, p 166.
27. *Ibid.*, p 164.
28. *Ibid.*, p 165.

APPENDIX
TRANSMISSION SPECTRA

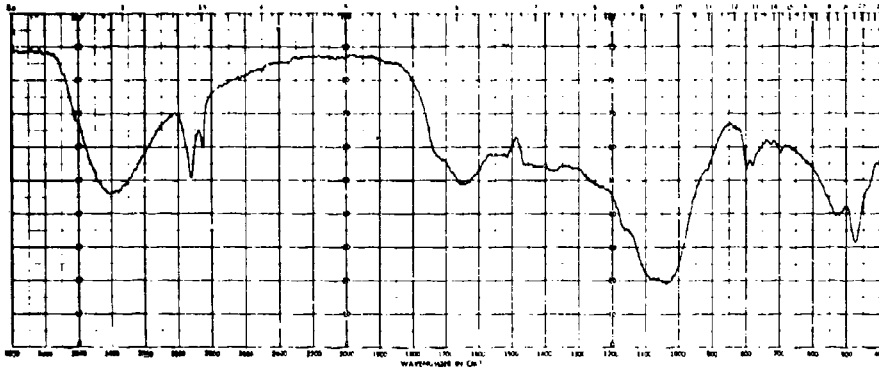


Figure A-1. Barrow, Alaska

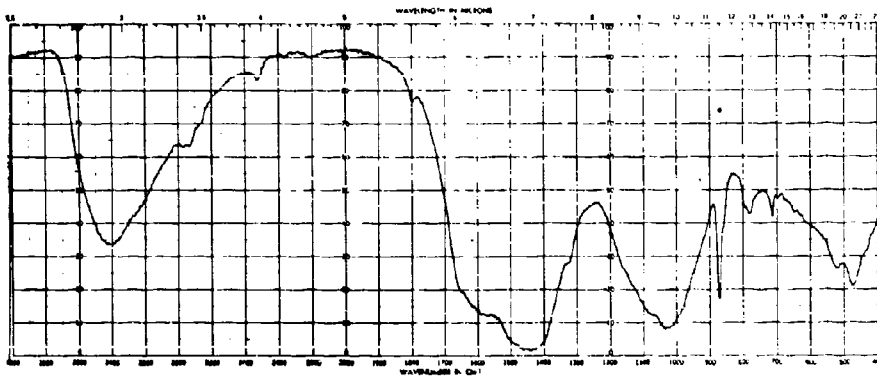


Figure A-2. Vadsø, Norway

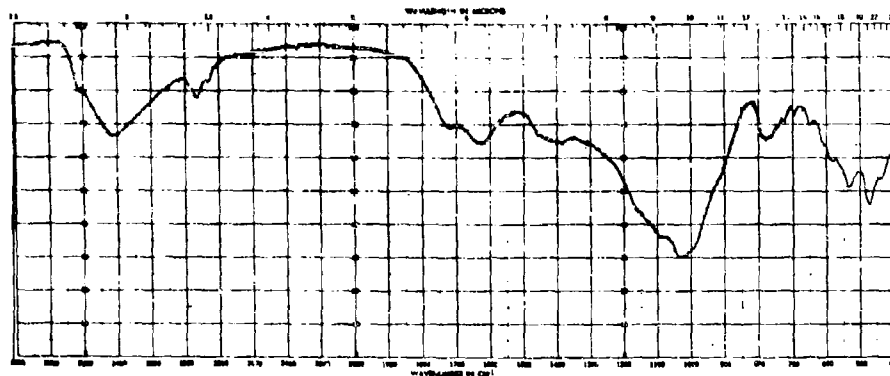


Figure A-3. Baroufoss, Norway

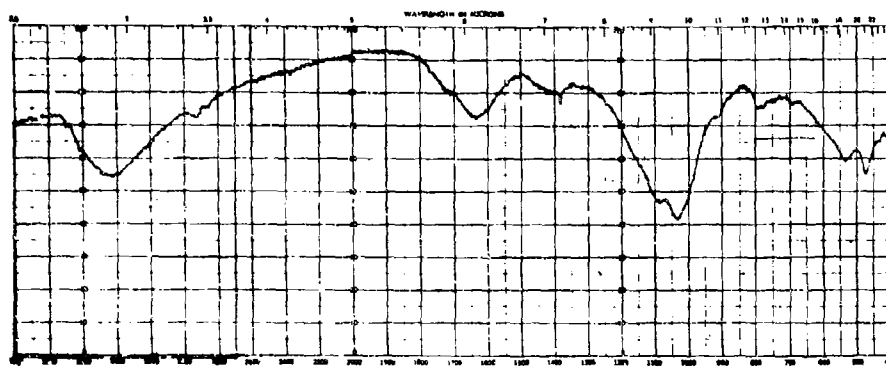


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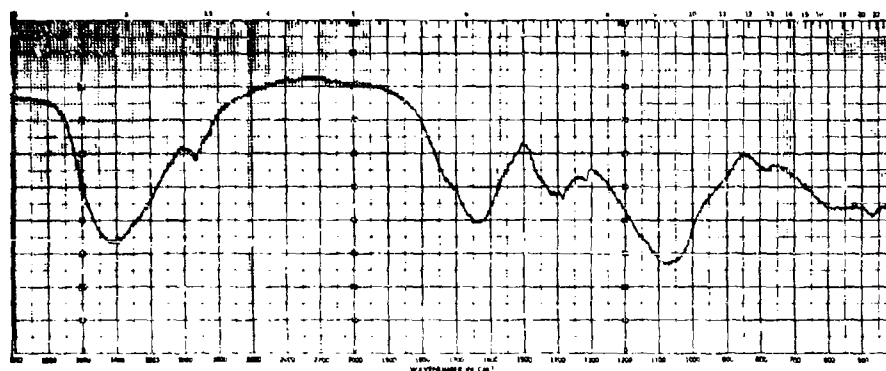


Figure A-5. Reykjavik, Iceland

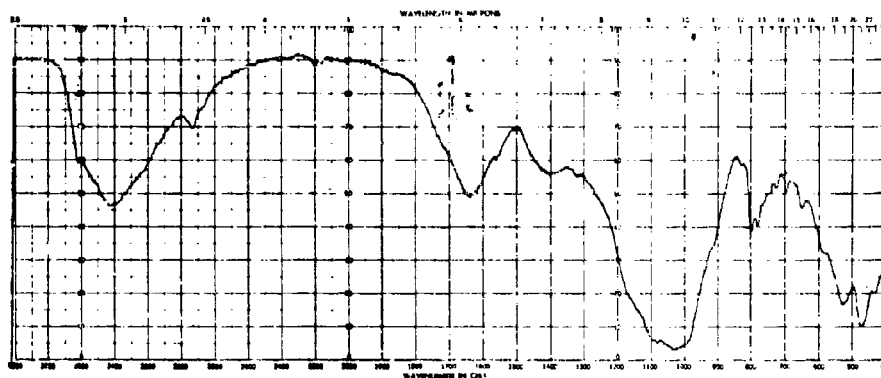


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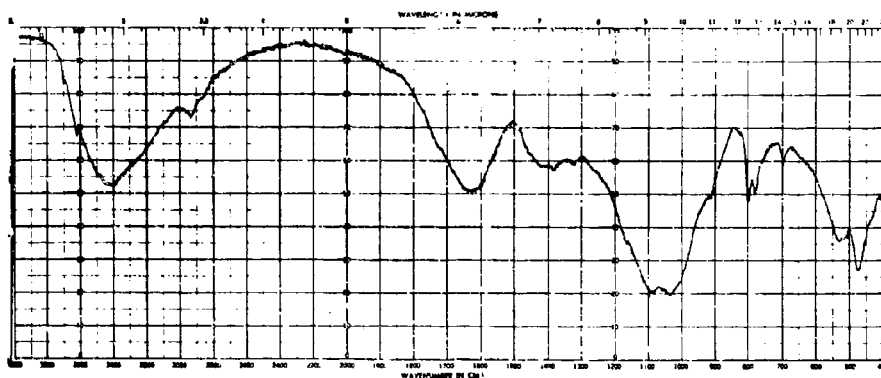


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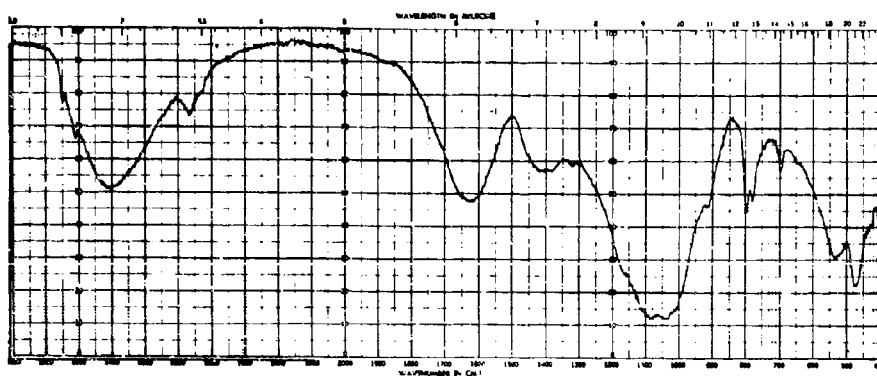


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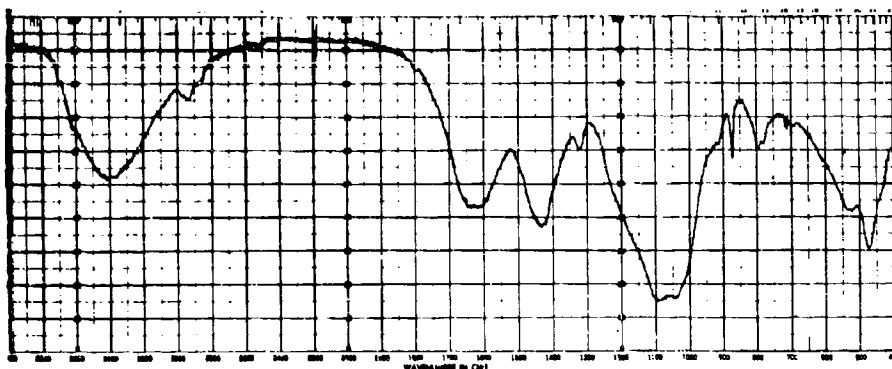


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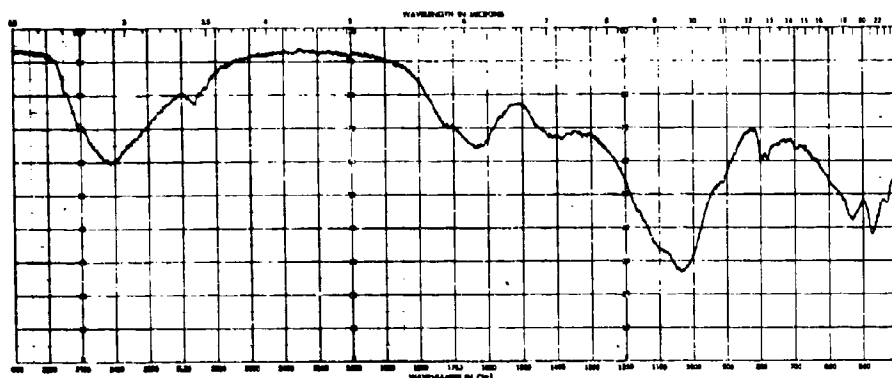


Figure A-10. Port Angeles, Washington

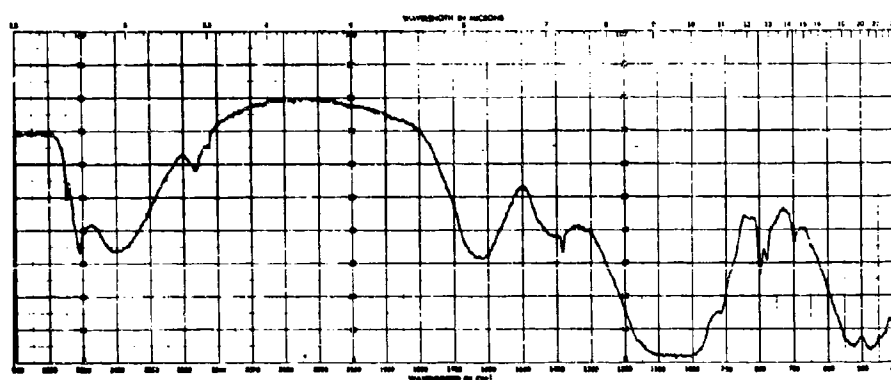


Figure A-11. Mandan, North Dakota

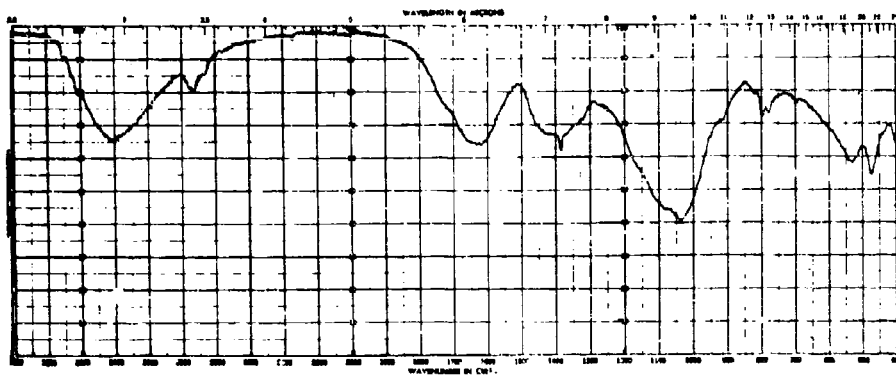


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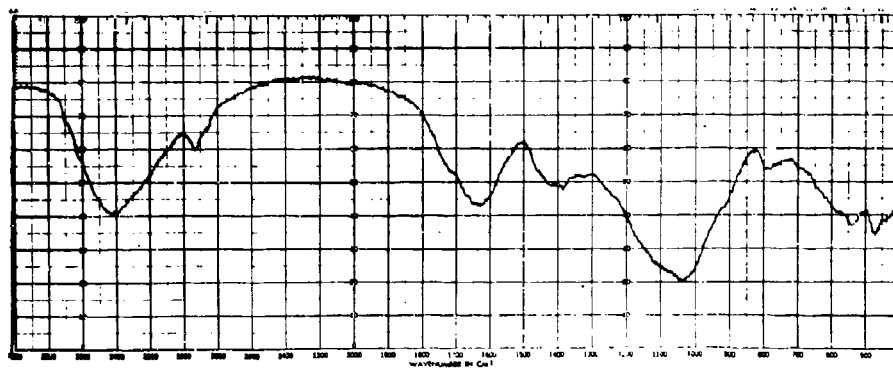


Figure A-13. Longview, Washington

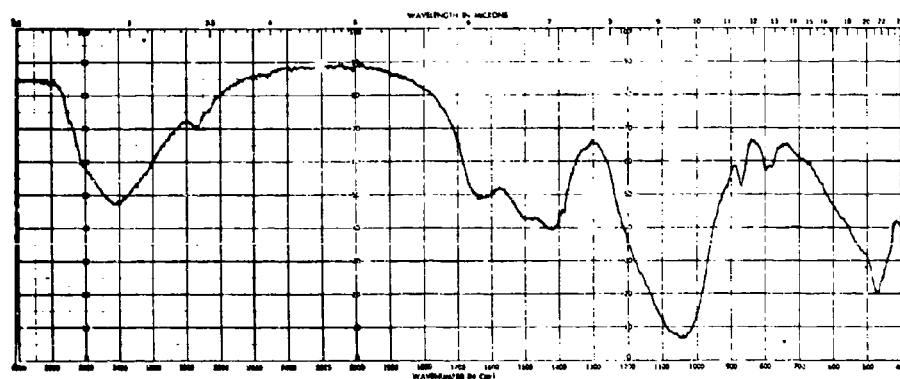


Figure A-14. Bozeman, Montana



Figure A-15. St. Paul Minnesota

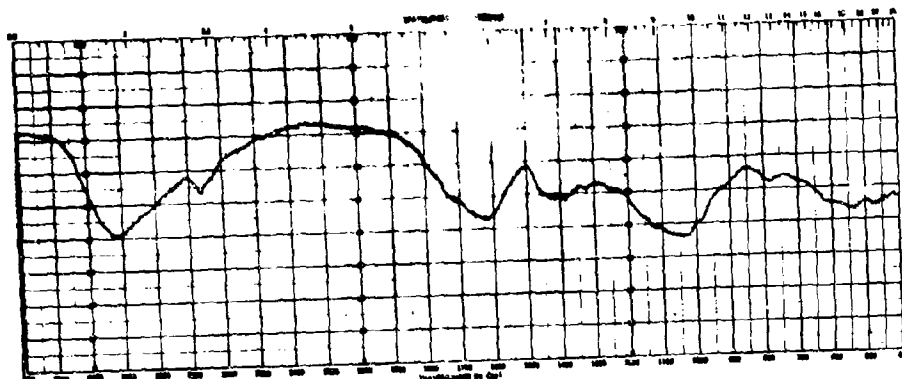


Figure A-16. Orono, Maine



Figure A-17. Corvallis, Oregon

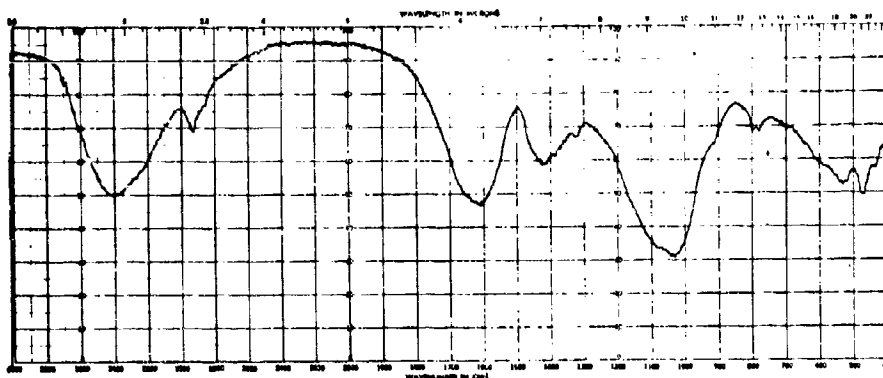


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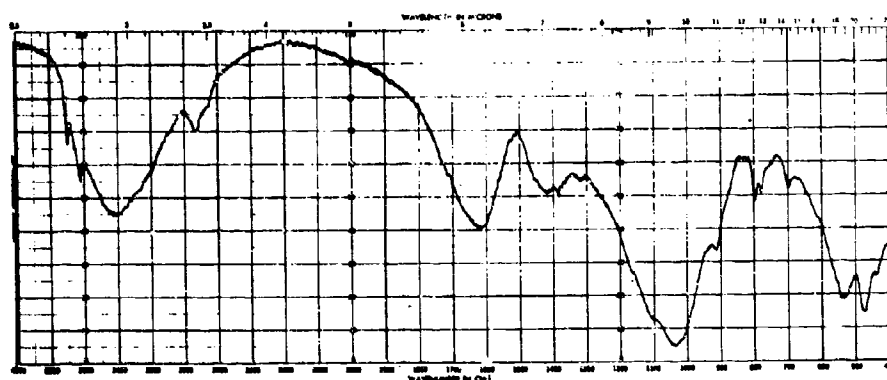


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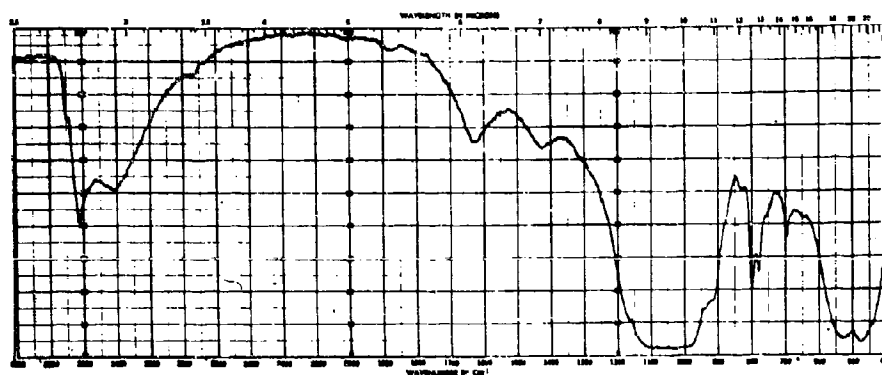


Figure A-20. Florence, Italy

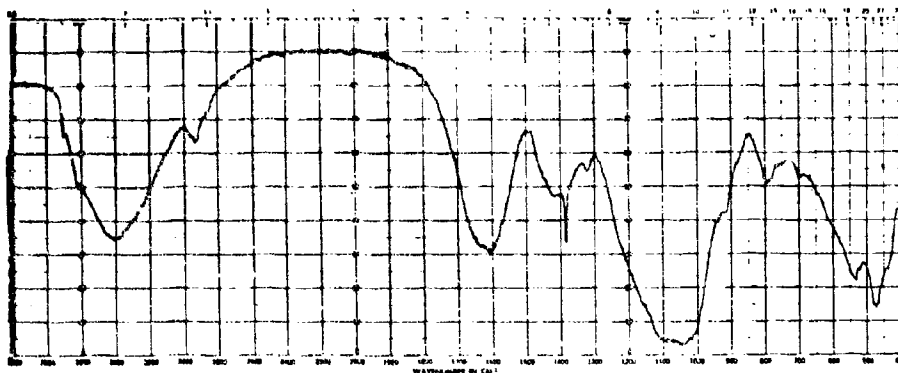


Figure A-21. Bois , Idaho

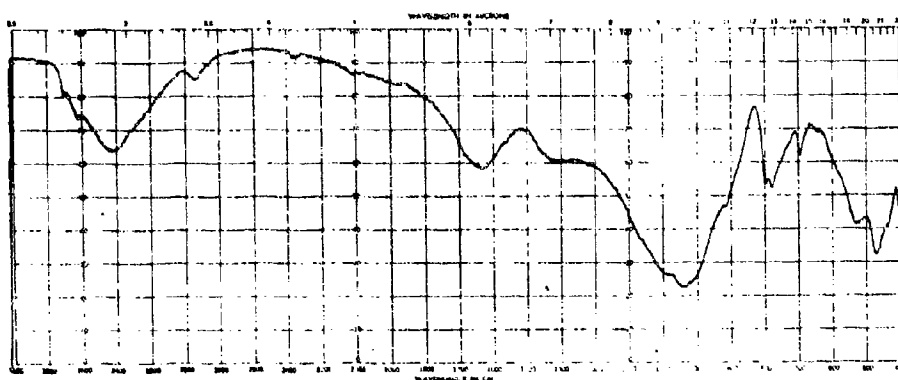


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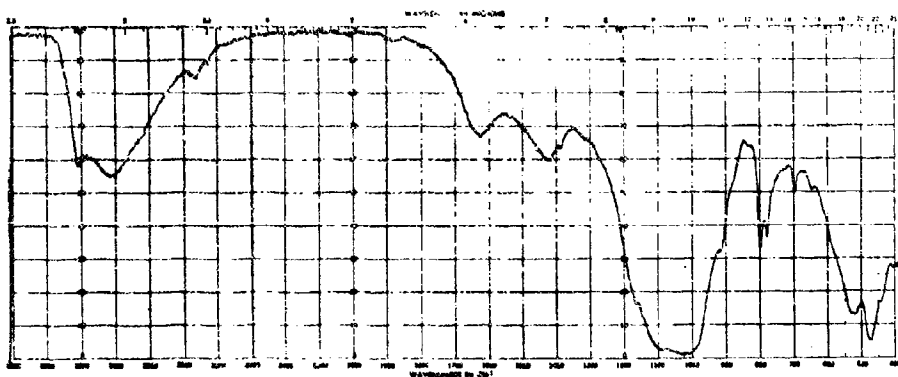


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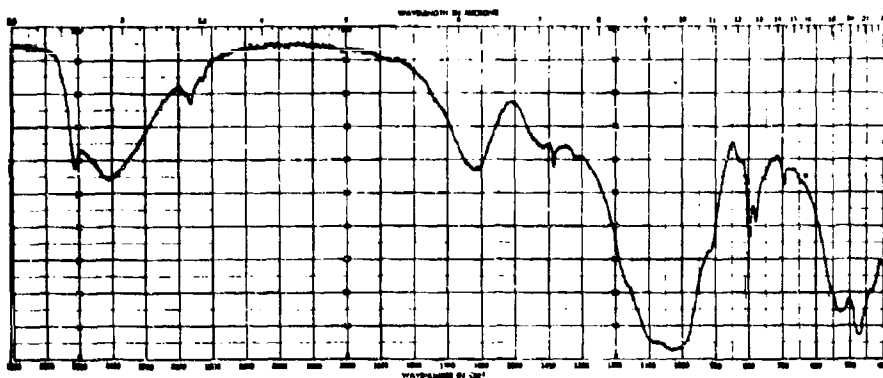


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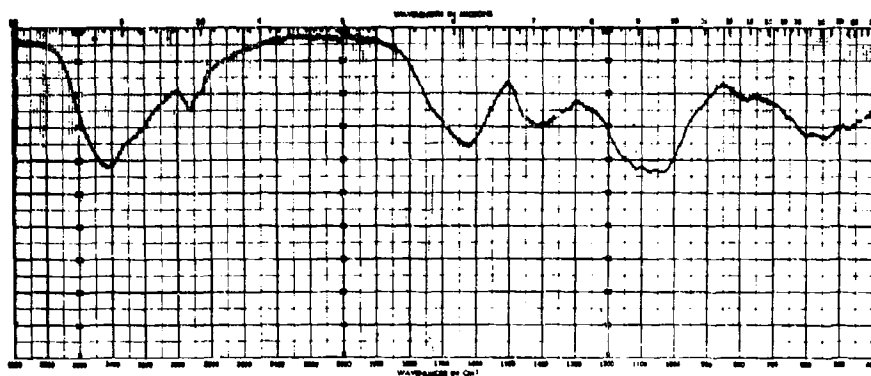


Figure A-25. Amherst, Massachusetts

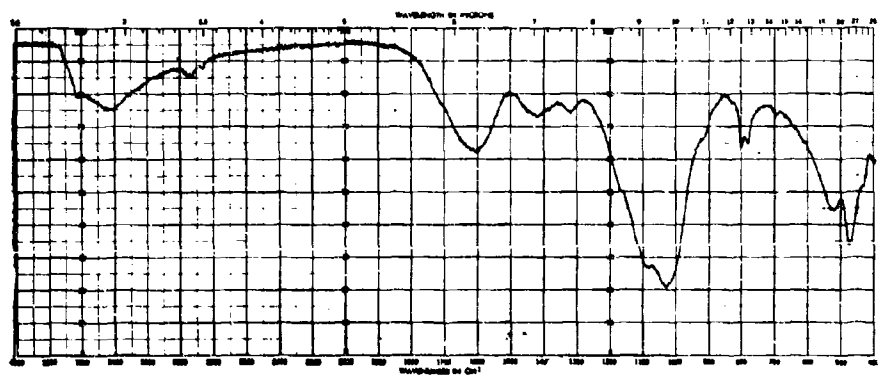


Figure A-26. Detroit, Michigan

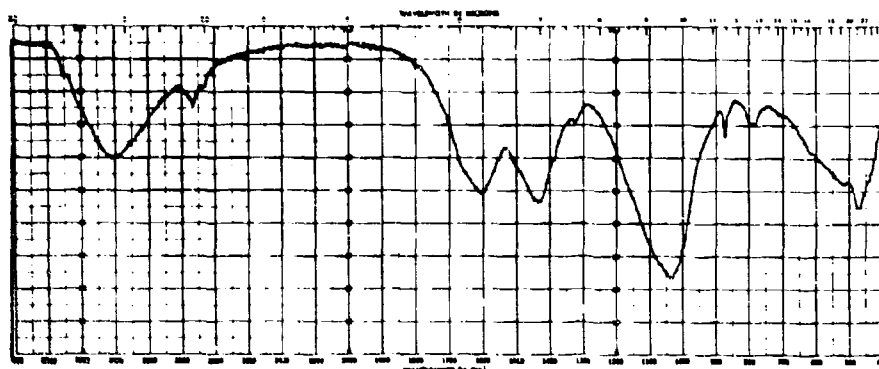


Figure A-27. Logan, Utah

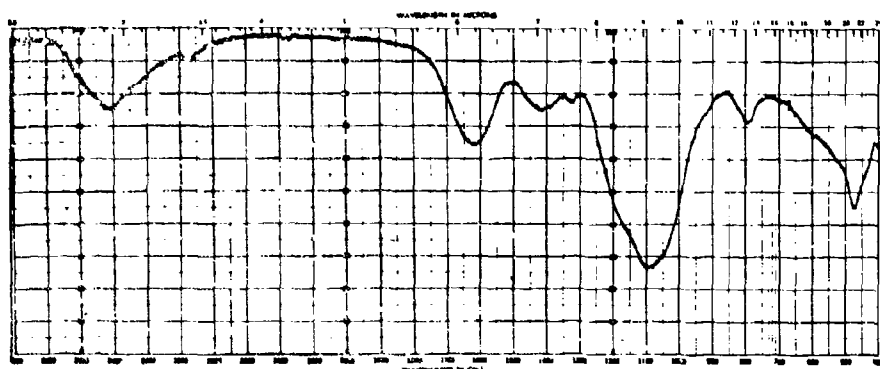


Figure A-28. Des Moines, Iowa

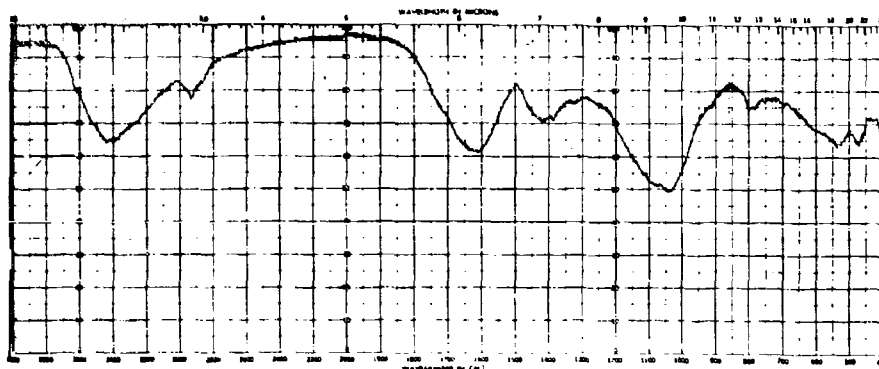


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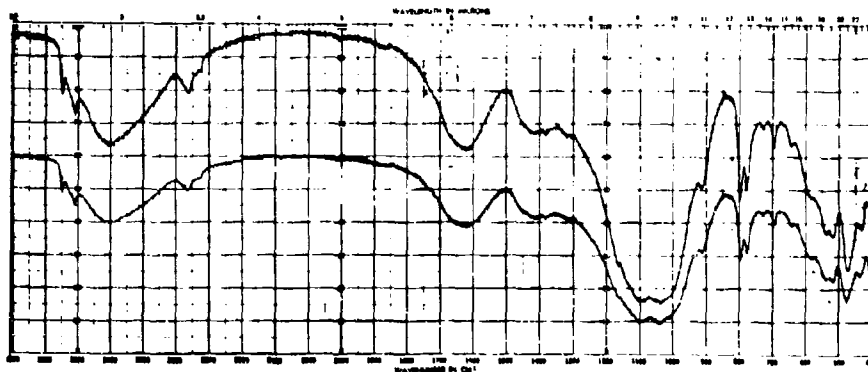


Figure A-30. University Park, Pennsylvania

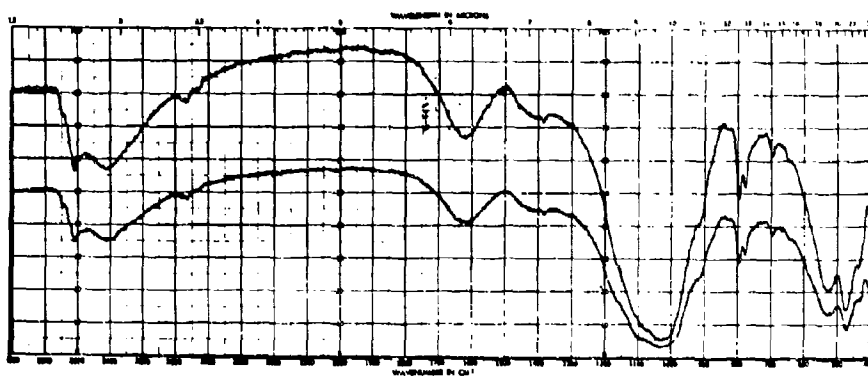


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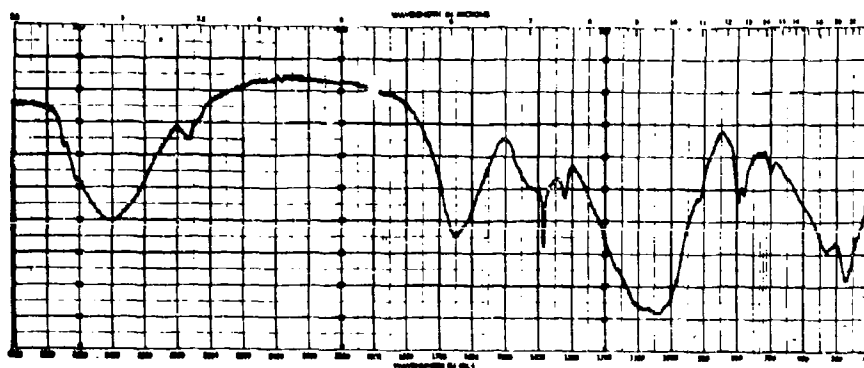


Figure A-32. New Brunswick, New Jersey

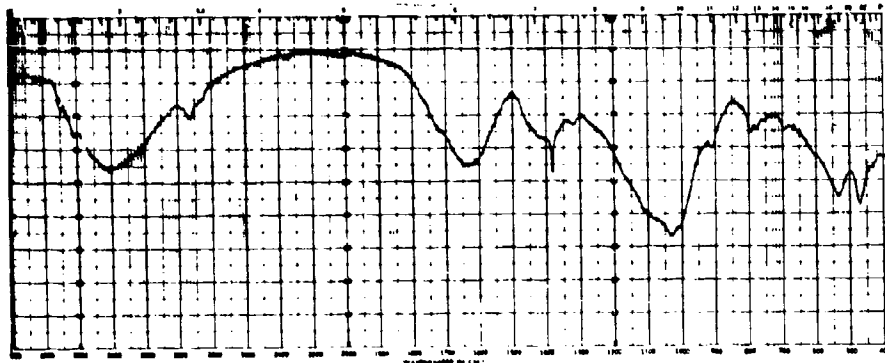


Figure A-33. West Lafayette, Indiana

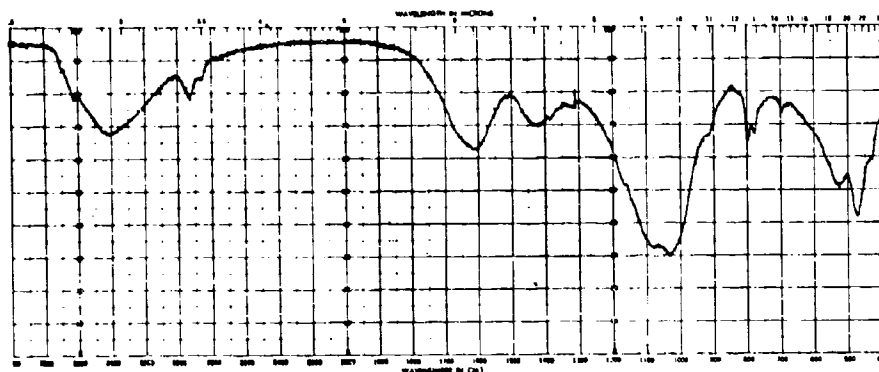


Figure A-34. Columbus, Ohio

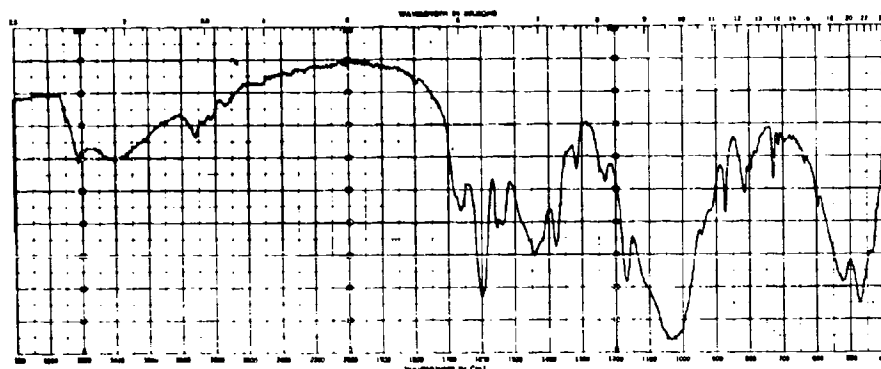


Figure A-35. Ankara, Turkey

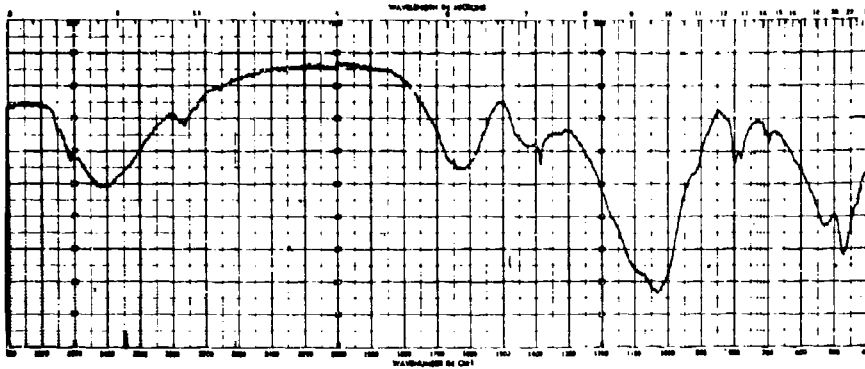


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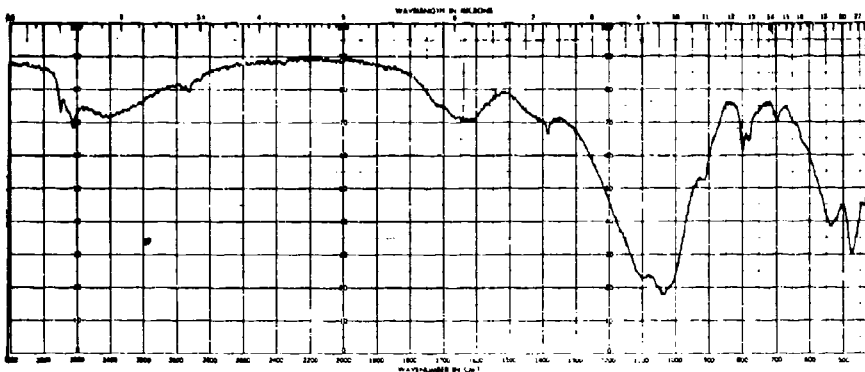


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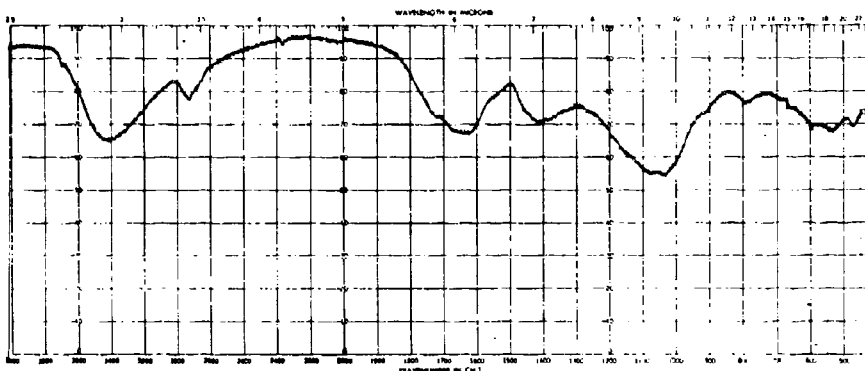


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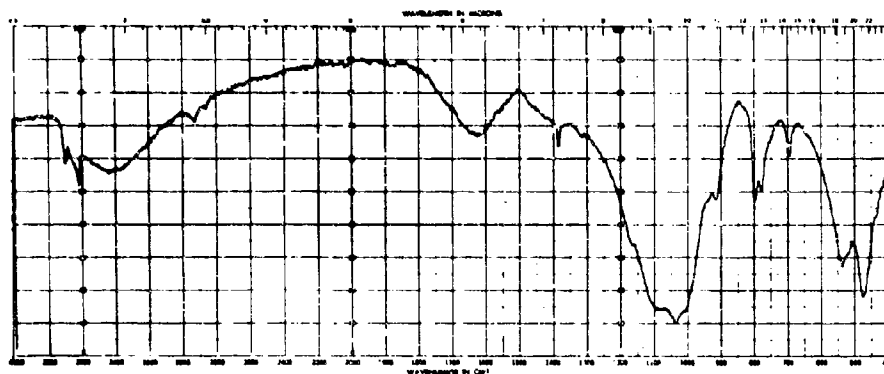


Figure A-39. Morgantown, West Virginia

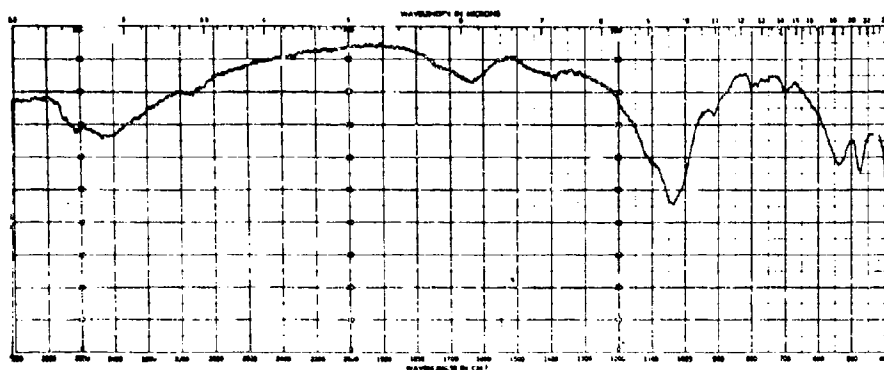


Figure A-40. Manhattan, Kansas

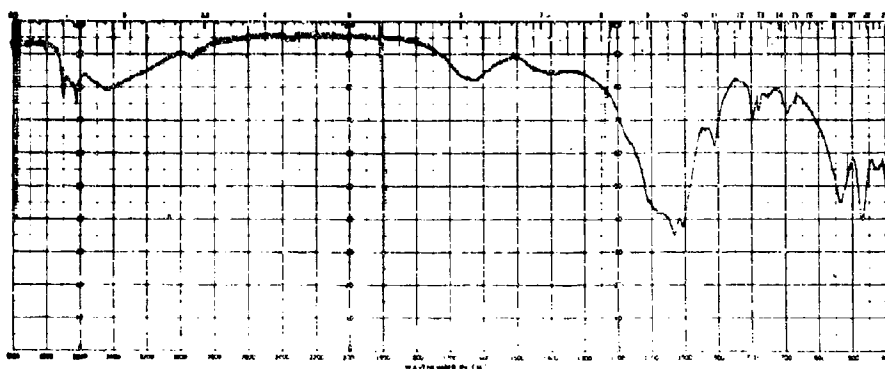


Figure A-41. Baltimore, Maryland

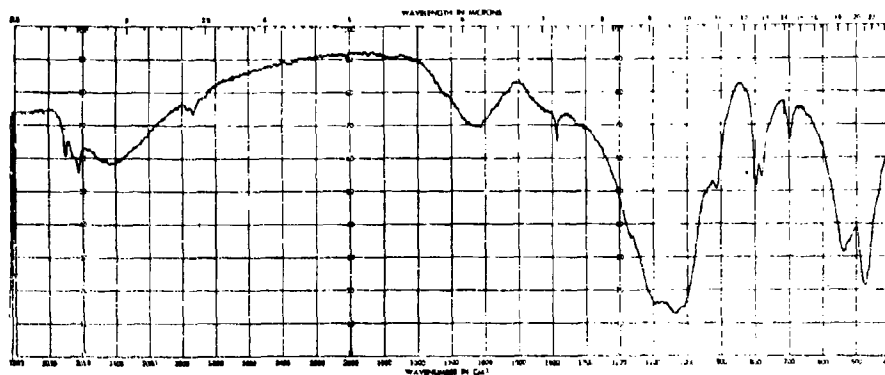


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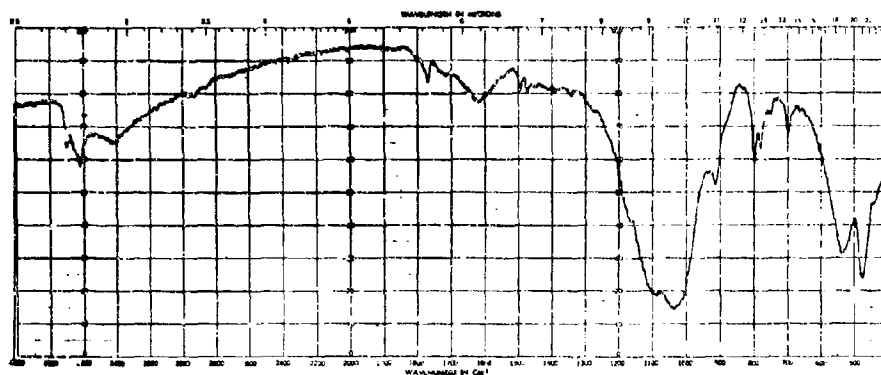


Figure A-43. Tulsa, Oklahoma

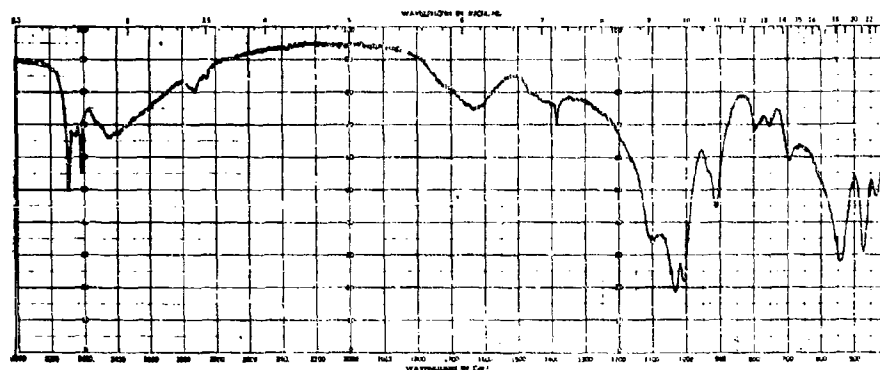


Figure A-44. Raleigh, North Carolina

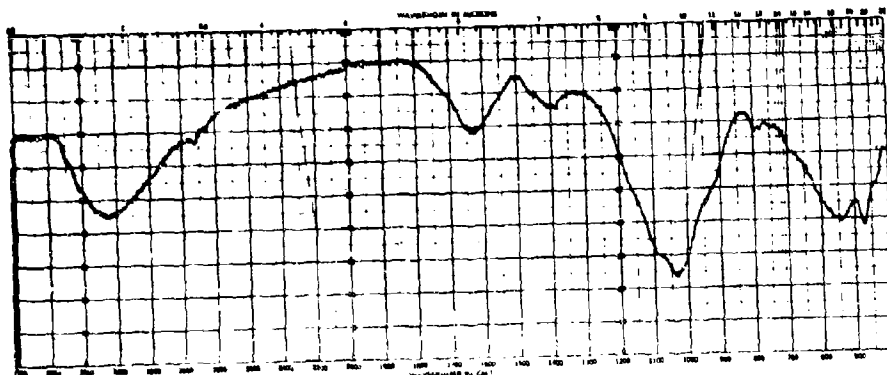


Figure A-45. Tokyo, Japan

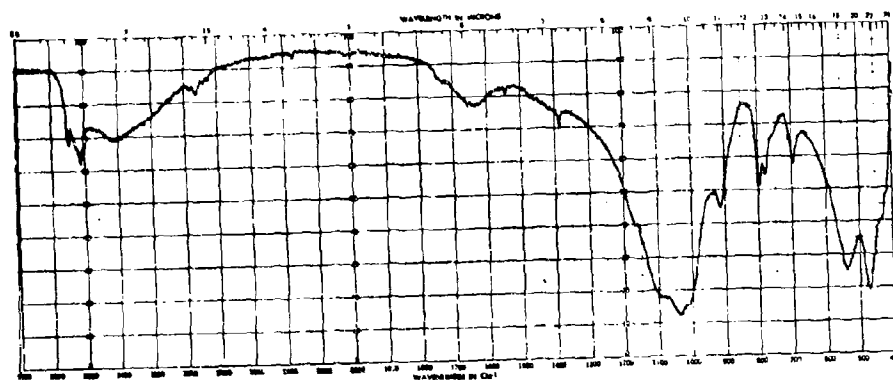


Figure A-46. Little Rock, Arkansas

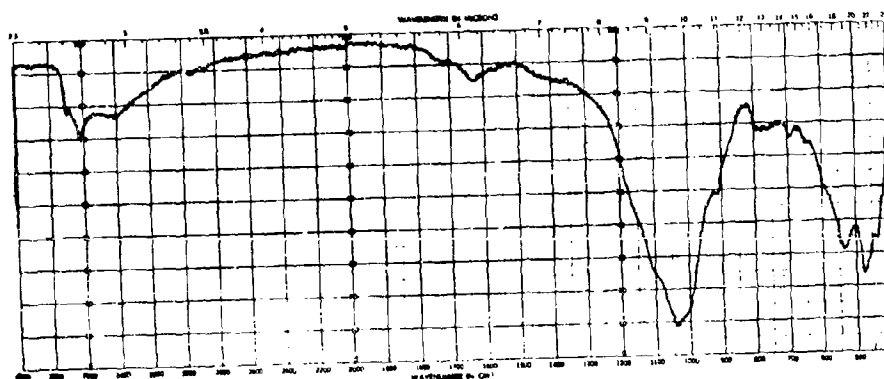


Figure A-47. Los Angeles, California

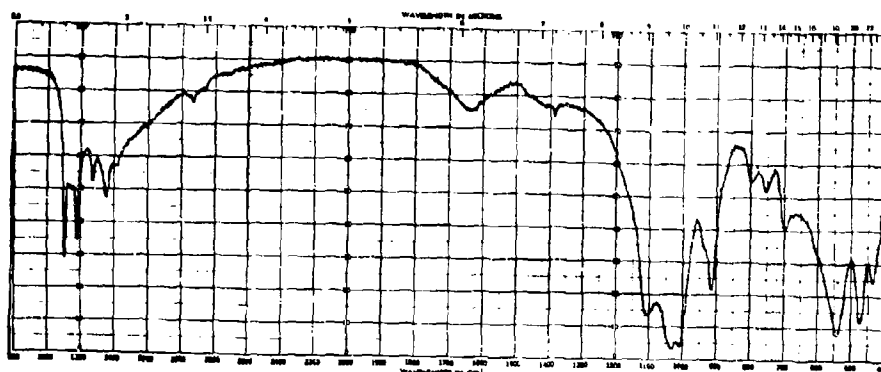


Figure A-48. Atlanta, Georgia

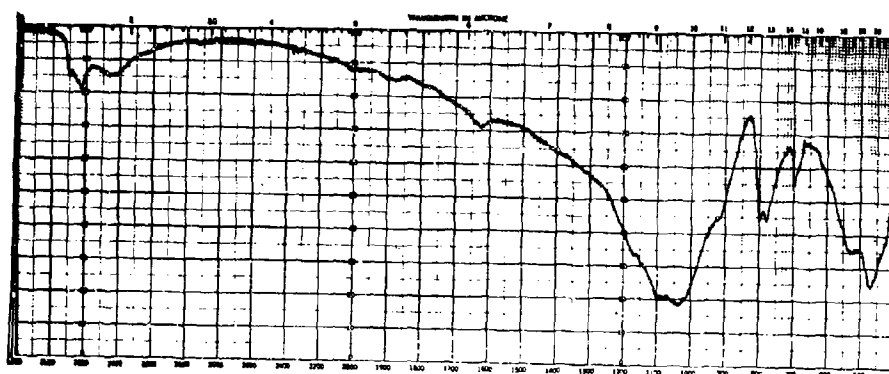


Figure A-49. Newton, Mississippi

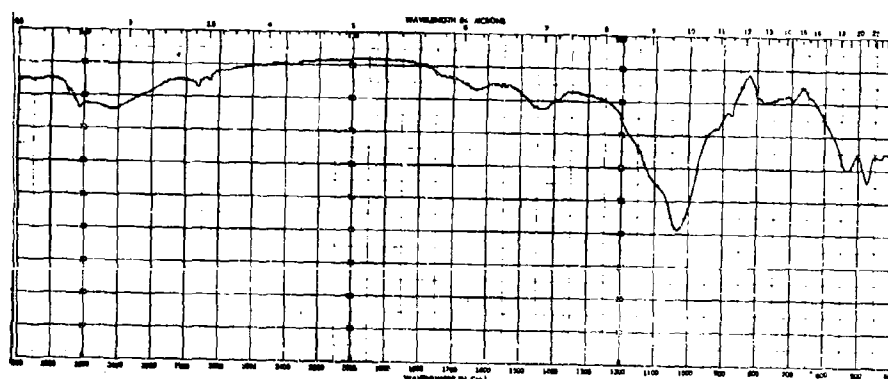


Figure A-50. Tucson, Arizona

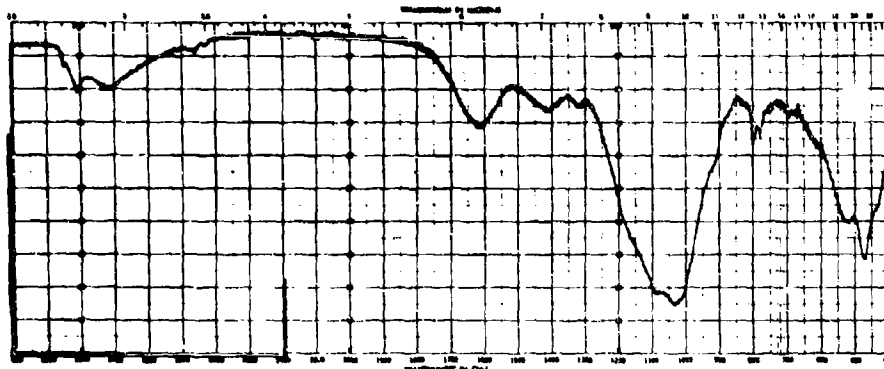


Figure A-51. Waco, Texas

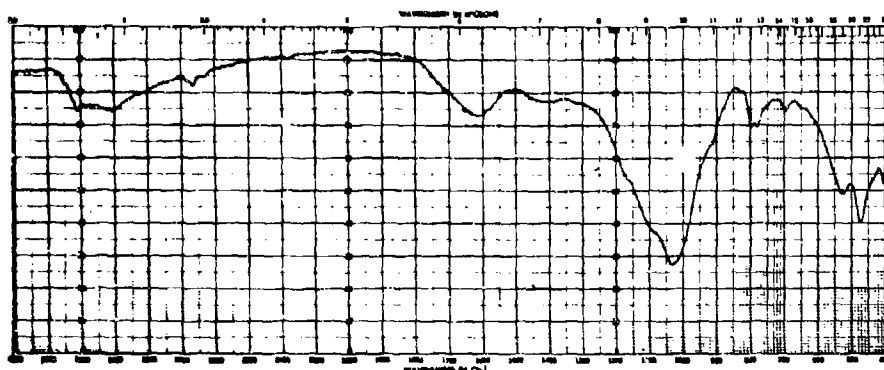


Figure A-52. Alexandria, Louisiana

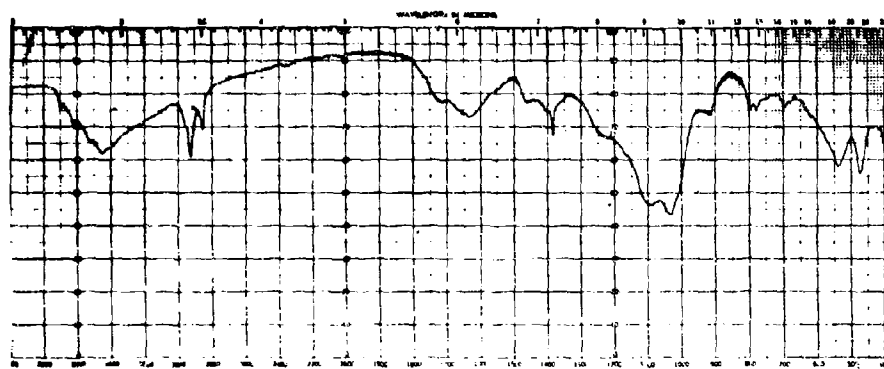


Figure A-53. Jacksonville, Florida

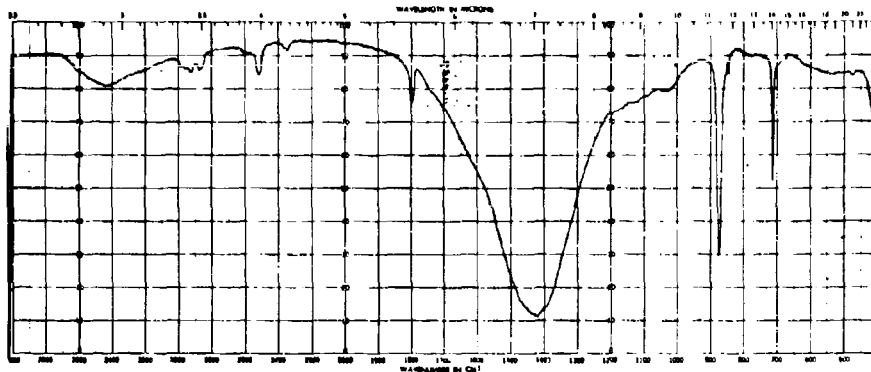


Figure A-54. South Miami, Florida

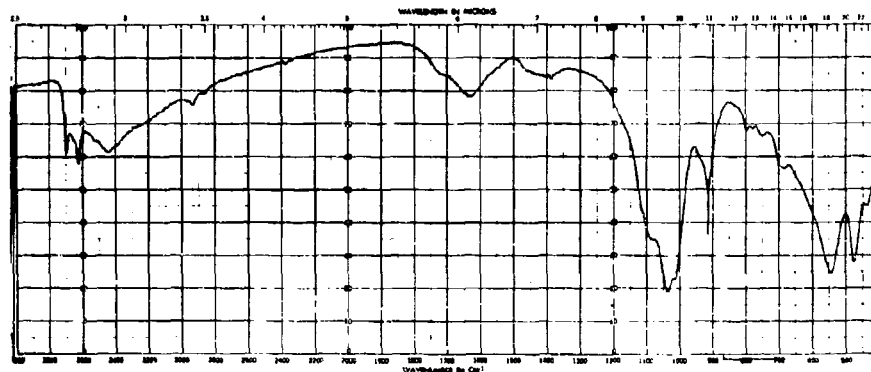


Figure A-55. Oahu, Hawaii

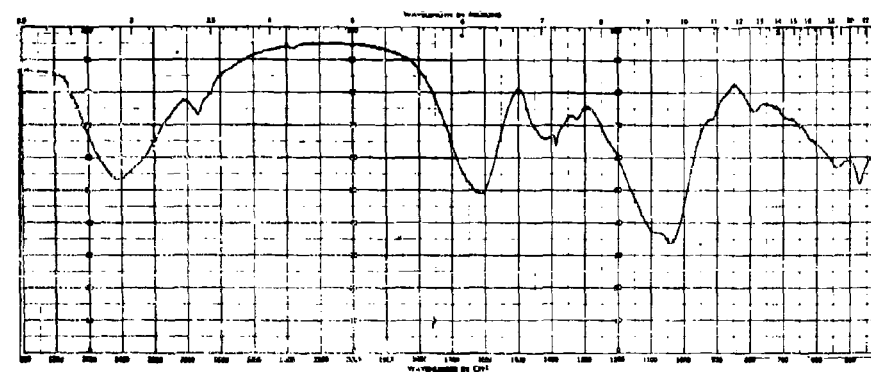


Figure A-56. Manila, The Philippines

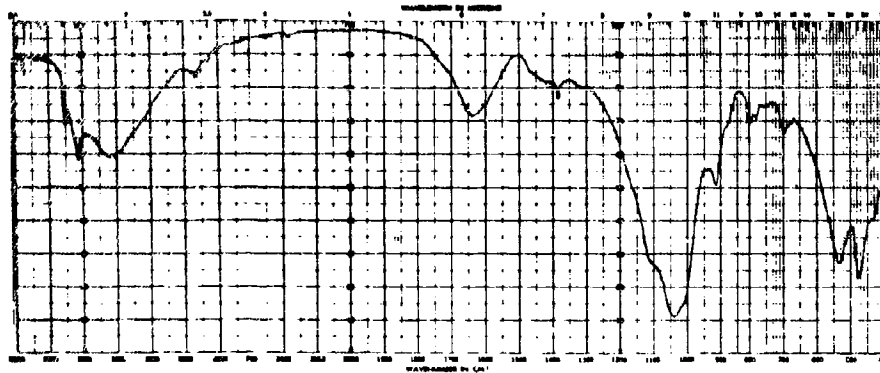


Figure A-57. Panama Canal Zone

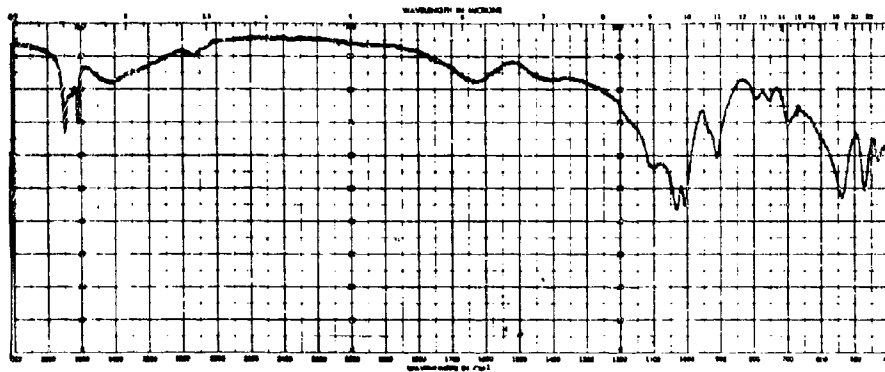


Figure A-58. Leedon Park, Singapore

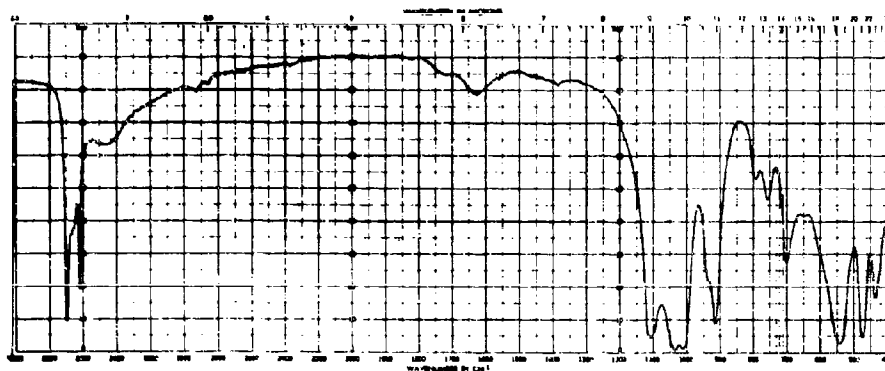


Figure A-59. Singapore

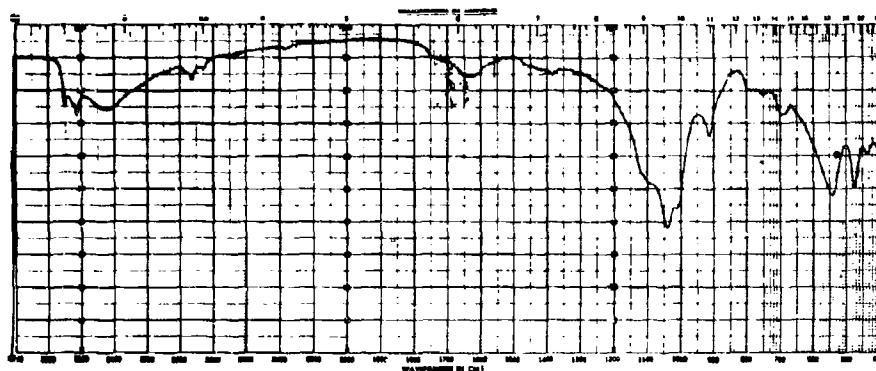


Figure A-60. Muguga, Kenya

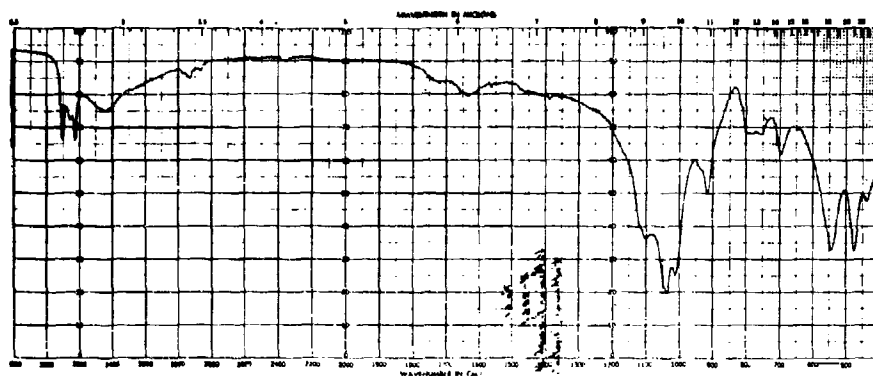


Figure A-61. Katherine, Australia

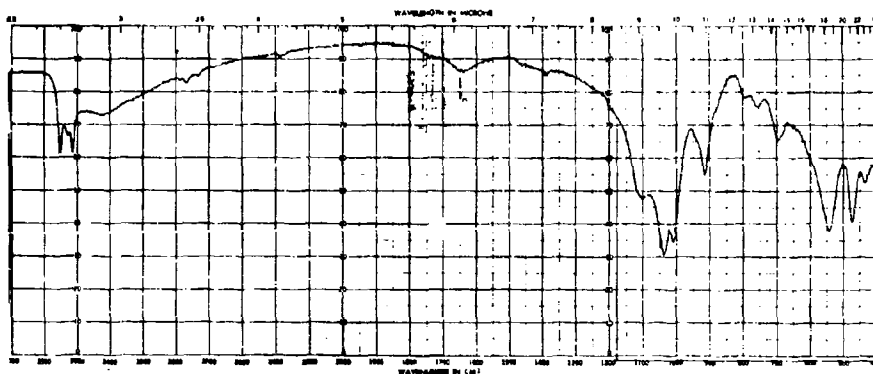


Figure A-62. Salisbury, Southern Rhodesia

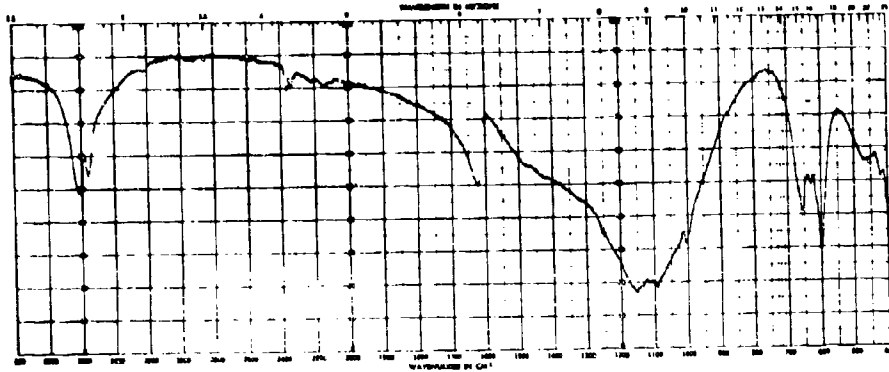


Figure A-63. Antofagasta, Chile

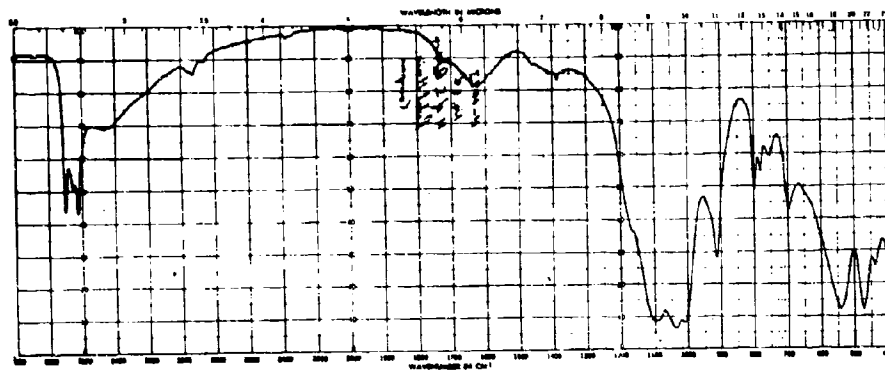


Figure A-64. Durban, Union of South Africa

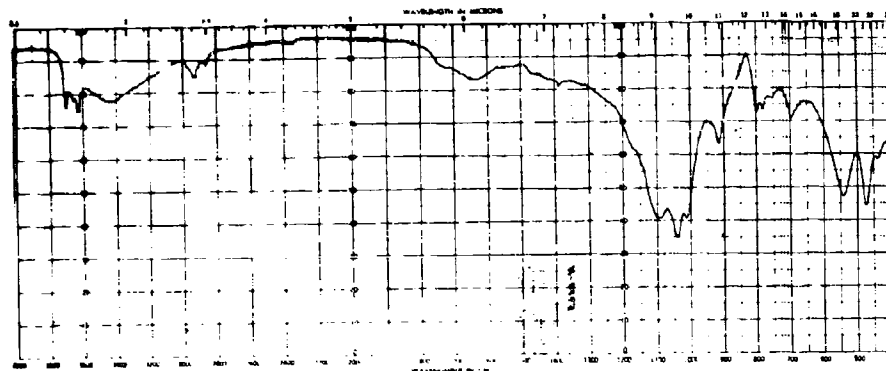


Figure A-65. North Auckland, New Zealand

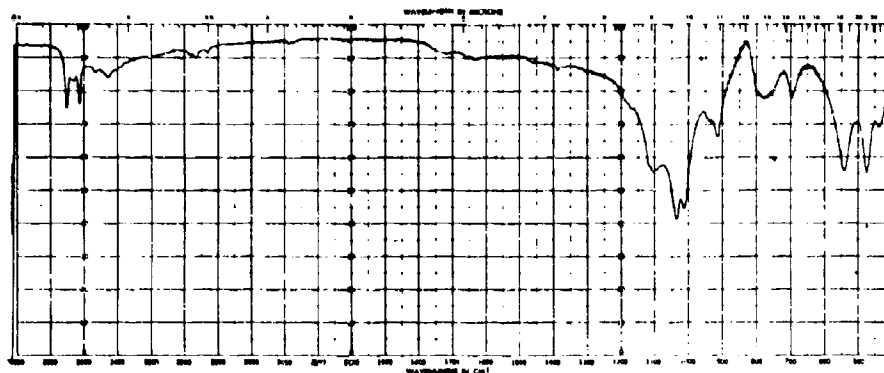


Figure A-66. Ft. McClellan, Alabama

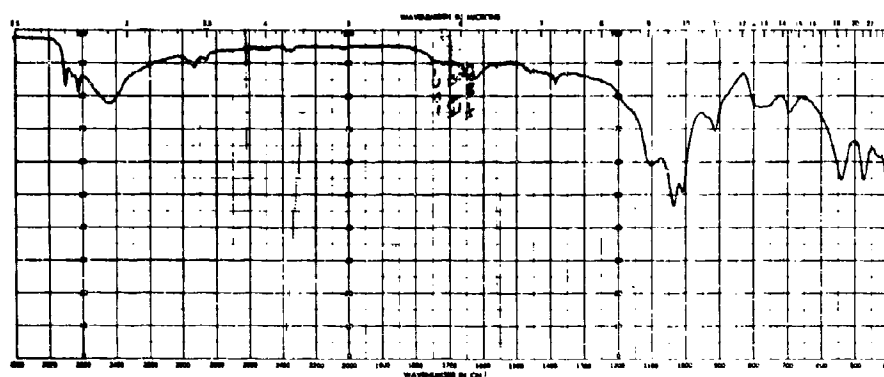


Figure A-67. Ft. Benning, Georgia

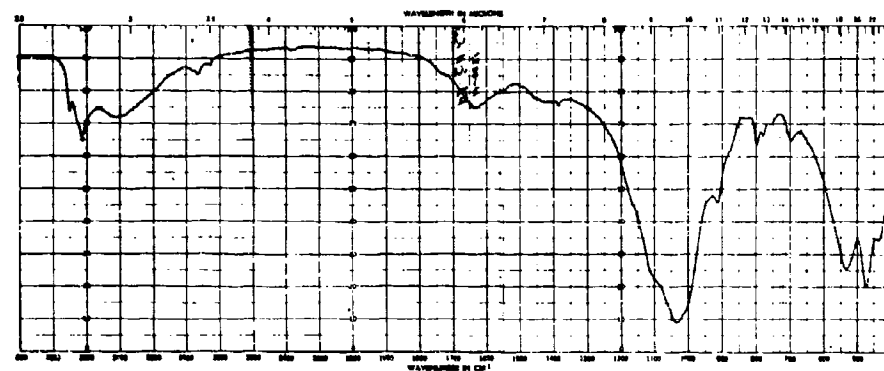


Figure A-68. Ft. Sill, Oklahoma

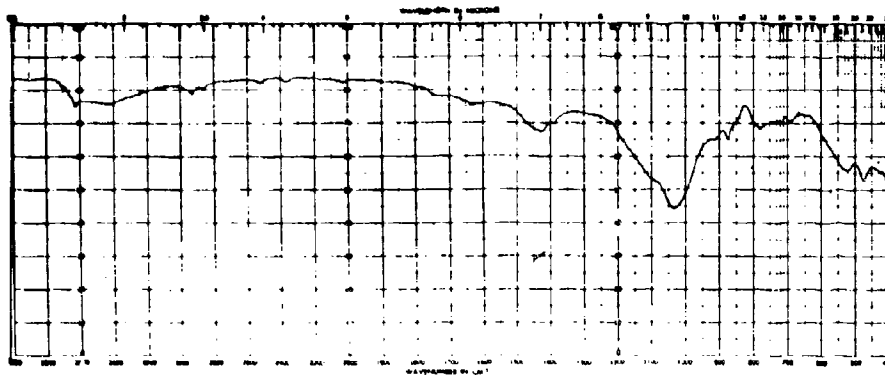


Figure A-69. Yuma Proving Grounds, Arizona

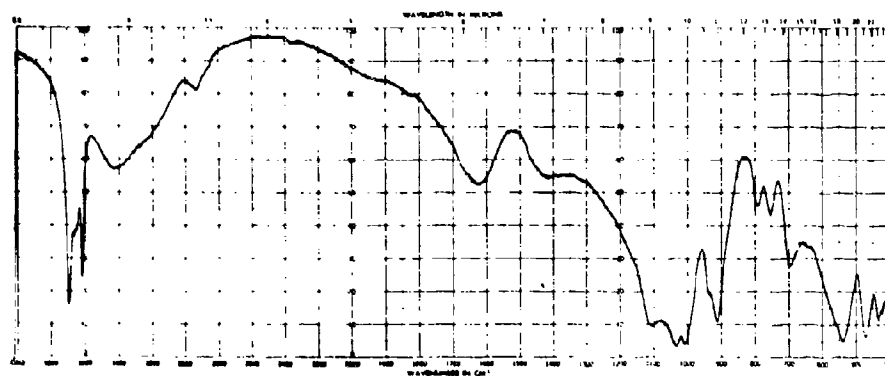


Figure A-70. Edgewood Arsenal, Maryland

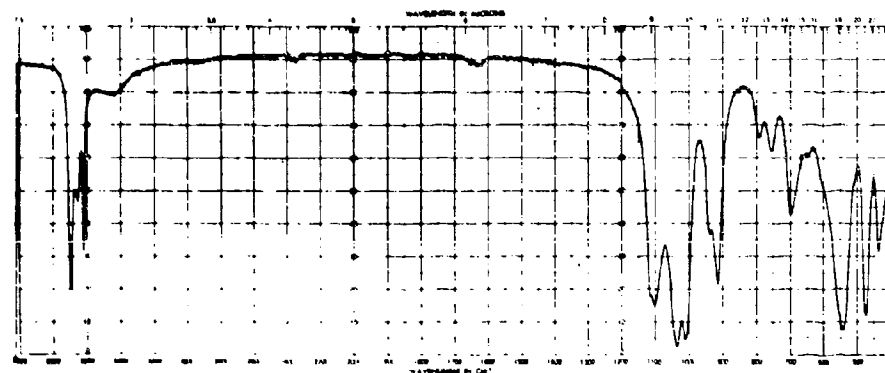


Figure A-71. Georgia Kaolin, Industrial

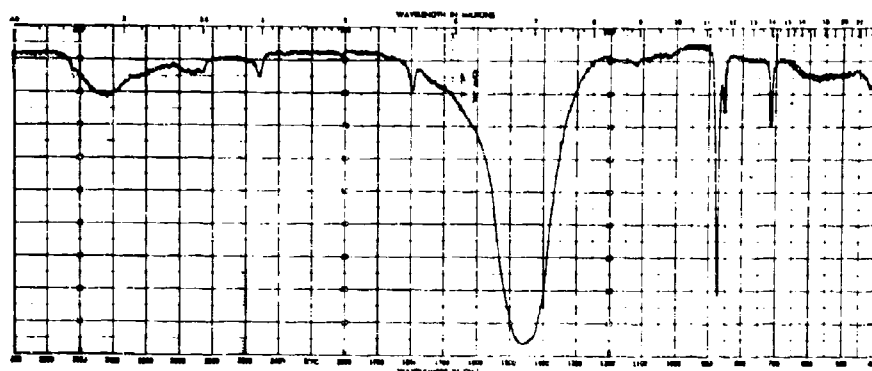


Figure A-72. Calcium Carbonate, Industrial

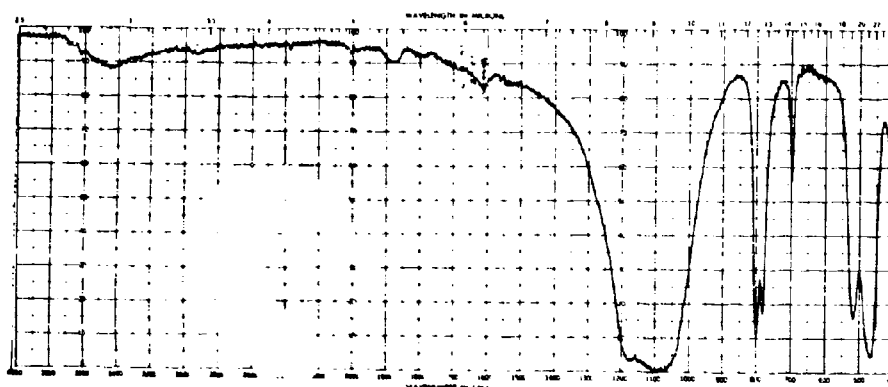


Figure A-73. Silica, Industrial

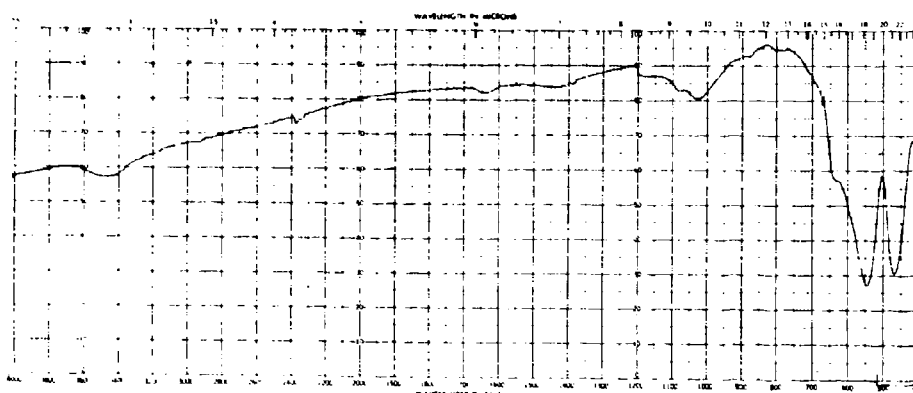


Figure A-74. Iron Oxide, Industrial

UNCLASSIFIED

Security Classification

DOCUMENT CONTROL DATA - R & D														
(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)														
1. ORIGINATING ACTIVITY (Corporate author) CO, Edgewood Arsenal ATTN: SMJEA-DDW-2 Edgewood Arsenal, Maryland 21010		2a. REPORT SECURITY CLASSIFICATION UNCLASSIFIED												
		2b. GROUP NA												
3. REPORT TITLE SPECTRAL ABSORPTION CHARACTERISTICS OF THE MAJOR COMPONENTS OF DUST CLOUDS														
4. DESCRIPTIVE NOTES (Type of report and inclusive dates) The work was performed from May 1968 through December 1969.														
5. AUTHOR(S) (First name, middle initial, last name) Dennis F. Flanigan Harry P. DeLong														
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c. Task No. 10622401A10202	9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report) NA													
d.														
10. DISTRIBUTION STATEMENT This document has been approved for public release and sale; its distribution is unlimited.														
11. SUPPLEMENTARY NOTES Chemical Agent Warning and Detection Techniques		12. SPONSORING MILITARY ACTIVITY NA												
13. ABSTRACT It is well known that dust clouds selectively absorb radiation in the 700 to 1300 cm^{-1} atmospheric window region. Studies have shown that dust clouds are composed of the same minerals as surface soils, although in different proportion. We have examined 70 soil samples from a number of locations around the world to determine their compositions and spectral characteristics. The results indicate that there are five major components that selectively absorb radiation in the 700 to 1300 cm^{-1} region. These are three clay minerals, silica, and calcium carbonate. Absorptivity coefficient spectra of representative soil samples are given in the body of the report, and transmission spectra of all soil samples are given in the appendix.														
14. KEYWORDS <table border="0"><tr><td>Atmospheric transmission</td><td>Illite</td></tr><tr><td>Dust clouds</td><td>Soil</td></tr><tr><td>Infrared</td><td>Montmorillonite</td></tr><tr><td>Clay minerals</td><td>Silica</td></tr><tr><td>Kaolinite</td><td>Calcium carbonate</td></tr><tr><td>Interference</td><td>Absorptivity</td></tr></table>			Atmospheric transmission	Illite	Dust clouds	Soil	Infrared	Montmorillonite	Clay minerals	Silica	Kaolinite	Calcium carbonate	Interference	Absorptivity
Atmospheric transmission	Illite													
Dust clouds	Soil													
Infrared	Montmorillonite													
Clay minerals	Silica													
Kaolinite	Calcium carbonate													
Interference	Absorptivity													

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